WESTON®

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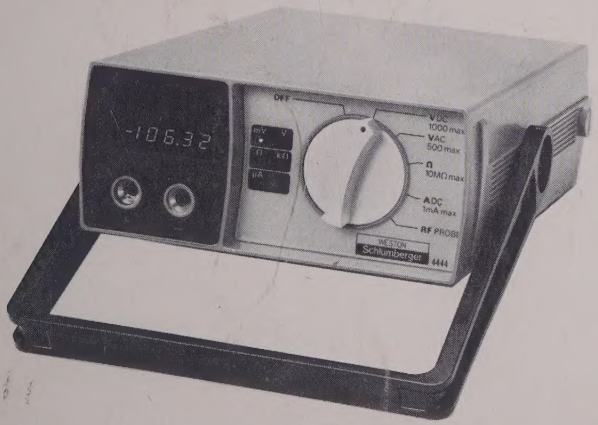
AUTO-RANGING
DIGITAL MULTIMETER



MODEL
4444

INSTRUCTIONS/PARTS LIST

STOP

IN CASE YOU ARE IN A HURRY TO USE YOUR NEW WESTON DIGITAL MULTIMETER (DMM).

1. Check that the red voltage selection indicator on the rear panel is set to correspond with local power supply voltage. If necessary, remove the two rear thumb screws, carefully remove the back panel and reposition the selector as required.
2. Connect the line cord to the power line receptacle at the rear and secure it in place with the screw provided.
3. Switch the mode selector to OFF.
4. Connect the line cord to a power outlet.
5. Switch to VDC and allow to warm-up for 30 minutes. The display should light up along with the (mV) indicator. If the input jacks are shorted, the display will soon settle down to a reading of 0.00mV. If the input is open circuited, the display reading will drift.
6. The instrument will automatically adjust its ranging decimal point location, and annunciator reading between mV and V in accordance with input level.
7. To measure alternating voltages, switch to VAC. A small residue will be indicated unless the input is shorted. Allow 3 seconds for the display to settle down when successive voltages are significantly different. Units of measure are mV and V.
8. When measuring resistance, the instrument will read overrange when the input leads are open. Units of measure are ohms (Ω) and kilohms (kΩ).
9. When measuring DC current, the instrument will zero properly only with the input open circuited or driven by a high impedance. Units of measure are microamperes (μA). In the event of overload, a front panel fuse behind the + input jack may be removed and replaced, using a rear thumb screw as a wrench.
10. RF probe operation is significant only with an RF probe accessory.
11. In the event of an overrange signal, the display will blank everything but a steady 1 in the 10000 position. An exception is the DC mA mode where the 1 and the μA lamp blink, with all else blanked.
12. **Caution:** Do not float the instrument more than 500V DC or peak above power ground.

INSTRUCTIONS WITH PARTS LIST

FOR

MODEL 4444

AUTO-RANGING DIGITAL MULTIMETER

U.S. Patent 3,051,939; 3,678,506
and Patents Pending

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WESTON INSTRUMENTS, INC.

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WESTON
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F-3793-999

Printed in U.S.A.

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SECTION 1

GENERAL INFORMATION

DESCRIPTION

The Weston Model 4444 is a 4 digit auto-ranging multimeter designed for either field use or laboratory applications. It is packaged in a light-weight shock-proofed impact-resistant plastic case. Its carrying handle carries a dual purpose as a tilt-stand for bench use. It may also be panel mounted using accessory brackets.

The combinations of a novel solid state auto-ranging A/D converter and a custom designed relay (for highest voltage ranges) permits five DC and AC voltage ranges with a minimum sensitivity of 10 microvolts and full scale ranges of 1000 volts DC and 500 volts AC. In addition, it features 5 ohms ranges from 1 kilohm to 10 megohms and 3 sensitive DC current ranges extending from 1mA down to 10μA full scale. An RF probe accessory extends the frequency span on AC volts to 300MHz. A LED display provides a full scale of 10,000 counts with an overrange to 10999. The basic measuring circuit is a bipolar triple-slope A/D converter which has expanded upon the basic dual-slope concept to provide rapid range switching and better rejection of normal and common mode line frequency interference. The converter operates at full scale ranges of either 100mV, 1 volt or 10 volts. Upranging occurs automatically when count rises above 10999 and down ranging occurs when count falls below 1000. Exceptions to this occur below 1000 counts on the lowest range and above 10999 on the highest range. Beyond the 10 volt range, a relay is energized to introduce attenuation or switch scaling resistors on the voltage and resistance ranges.

The A/D converter is preceded by a chopper stabilized amplifier connected in a boot-strapped mode to provide very high input impedance. The same amplifier is used with other signal conditioning circuitry to convert all measurands to one of the three DC ranges served by the A/D converter.

AC voltage is converted to DC by an average-sensing RMS-calibrated, operational rectifier. DC current is measured by direct conversion to voltage in an operational feedback circuit. To measure resistance, a scaled constant current is passed through the unknown and voltage across it measured by the A/D converter.

All functions are protected up to or beyond the limits of the maximum range. The current function is additionally protected by internal resistive limiting and a front-panel mounted fuse.

Power requirements are 115VAC or 230VAC at 50Hz or 60Hz. Power drain is 7 watts, nominal.

SECTION 2

SPECIFICATIONS

Display	Type: Light emitting diodes, 0.19" character size, 7 segment with integral decimal points. Maximum Count: 10999, with leading zero blanking. Polarity: Automatic, negative "-". Overrange Indication: Solitary "1" in 10000 place on DCV, ACV, ohms. Blinking "1" and μA lamp on DC current. Reading Rate: 2 to 3 per second Annunciators: Single LED lamps for each of mV, V, Ω, kΩ, and μA ranges.
Power Requirement	115/230VAC, +10%, -15% Line Frequency: 50/60Hz Power Drain: 7 watts nominal
Power Line Isolation	May be operated up to 500 volts peak or DC above power line ground with a leakage impedance no less than 1000 megohms.
Operating Temperature	0°C to 45°C
Storage Temperature	-30°C to +70°C
Humidity	70% at 40°C
Size	2.26"H x 5.43"W x 7.01"D
Weight	2.2 pounds

PERFORMANCE CHARACTERISTICS

The following accuracies are specified at temperatures within 1°C of the calibration temperatures, and line voltage of 115/230VAC ±10% and are achieved after not more than a 30 minute warm-up period.

DC VOLTS

Range	*Zin*	*Accuracy*	*Temperature Influence per °C*
100mV	1000MΩ	±0.02% Rdg ±2 digits	±0.004% Rdg ±0.2 digit/°C
1V	1000MΩ	±0.02% Rdg ±1 digit	±0.004% Rdg/°C
10V	1000MΩ	±0.02% Rdg ±1 digit	±0.004% Rdg/°C
100V	10MΩ	±0.03% Rdg ±1 digit	±0.007% Rdg/°C
1000V	10MΩ	±0.03% Rdg ±1 digit	±0.007% Rdg/°C

Maximum Input: 1000 volts DC or peak
Overrange Capability: to 10999 except on the 1000 volt range where the allowable maximum is 1000 volts peak.
Resolution: 10 microvolts
Input Current: 0.2nA maximum
Series Mode Rejection: At a frequency of 60Hz ±1% (60dB minimum)
Common Mode Rejection
(with 1 kilohm input unbalance): Rejection of DC ..... 120dB minimum
Rejection of 60Hz ±1% ..... 130dB minimum
Maximum allowable common mode voltage ..... 500VDC or peak

Reading Rate: 3 per second
Ranging Time: 1.5 second maximum
Residual ZERO reading after warm-up: ±1 count, typical, 2 counts max over 24 hours (measured with input shorted)

AC VOLTS (Mean sensing, RMS calibrated)

Range	*Accuracy (40Hz to 10kHz*	*Temperature Influence per °C*
100mV	±0.1% Rdg ±8 digits	±0.006% Rdg ±0.4 digit
1V	±0.1% Rdg ±4 digits	±0.006% Rdg
10V	±0.2% Rdg ±7 digits	±0.015% Rdg ±0.4 digit
100V	±0.2% Rdg ±3 digits	±0.015% Rdg
500V	±0.2% Rdg ±3 digits	±0.015% Rdg

Maximum Input: 700VRMS
Overrange Capability: to 10999 except on the 500 volt range where the allowable maximum is 700 volts RMS.
Resolution: 10 microvolts
Input Impedance: 1 megohm in parallel with 100 pF. This does not include the capacitance presented by an input cable.
Reading Rate: 2.5 per second
Ranging Time: 3 seconds maximum
Residual zero reading after warm-up: 6 counts maximum, after DCV is zeroed (measured with input shorted)

RESISTANCE

Range	*Current Applied*	*Accuracy*
1kΩ	100μA	±0.05% Rdg ±3 digits
10kΩ	100μA	±0.05% Rdg ±1 digit
100kΩ	100μA	±0.05% Rdg ±1 digit
1MΩ	1μA	±0.05% Rdg ±1 digit
10MΩ	1μA	±0.25% Rdg ±2 digits

Maximum Input: 200V peak, all ranges
Overrange Capability: 10999 on all ranges – Beyond 10999 kilohms, display blanks except for steady "1" in 10000 position.
Resolution: 0.1 ohm
Reading Rate: 3 per second
Ranging Time: 1.5 second maximum
Temperature Influence: ±0.003% Rdg/^{O}C ±0.2 digit/^{O}C
Residual zero reading after warm-up: 2 counts maximum after DCV is zeroed (measured with input shorted)

DC CURRENT

Range	*Accuracy*	*Temperature Influence per ^{O}C*
10μA	±0.05% Rdg ±3 digits	±0.007% Rdg ±0.2 digit
100μA	±0.05% Rdg ±1 digit	±0.007% Rdg
1mA	±0.05% Rdg ±1 digit	±0.007% Rdg

Maximum Input: 15 volts; protected beyond 15 volts by fuse input jack
Overrange Capability: 10999 maximum count on all ranges. Beyond 1099.9μA, the display is blanked except for a blinking "1" in the 10000 position and a blinking μA lamp.
Resolution: 1nA
Reading Rate: 3 per second
Ranging Time: 1.5 second maximum
Equivalent Shunt Resistance: Less than 100 ohms
Residual ZERO reading after warm-up: 1 count, maximum after DCV is zeroed (measured with input open)

RF PROBE

In the RF probe position the Model 4444 accepts current from an RF probe accessory unit which converts voltage to current. Internal function is similar to that of the DC amps. Ranges indicated are 1 volt and 10 volts depending on the probe used with the accessory converter.

SECTION 3

INSTALLATION

GENERAL

Inspect the instrument for possible damage in shipment. If damage is noted, notify the carrier and supplier before using the instrument.

CARRYING HANDLE-TILT STAND

The handle incorporates a detent mechanism to provide an adjustable tilt-stand for bench use.

PANEL INSTALLATION

The instrument is provided with an option for mounting on a panel. Special mounting hardware is available under Catalog No. 0274381. The dimensional drawing is shown in Figure 3-1 and panel cut-out dimensions are given in Figure 3-2.

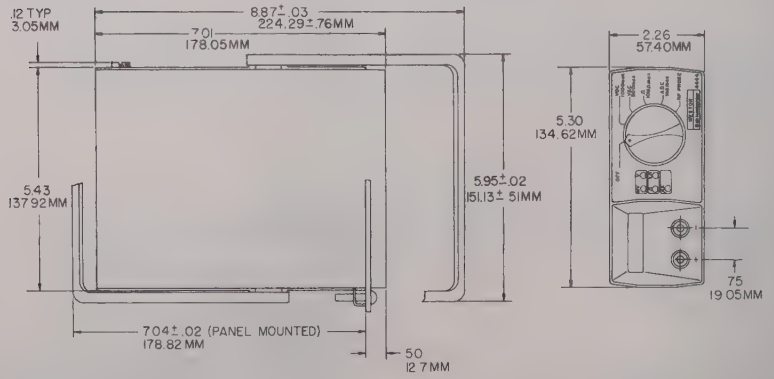


Figure 3-1. Dimensional Drawing

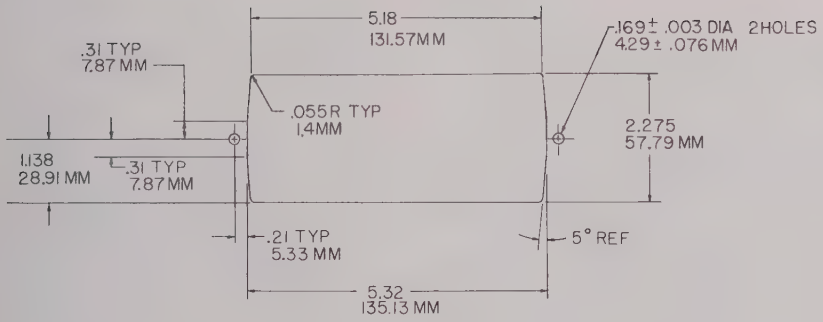


Figure 3-2. Panel Cut-Out Dimensions

LINE VOLTAGE SELECTION

The instrument can operate at nominal line voltage of 115VAC or 230VAC depending on the setting of a jumper plug accessible through the rear panel. It should be set to agree with local line voltage conditions before use. A red marker protruding through the rear panel will designate the setting. If a change in setting is required, remove the two thumb-screws which hold the rear panel in place and swing away the rear panel which is held by three jumper leads. Slide the circuit board assembly out about 2 inches to expose the red jumper connector block at the left rear of the bottom board. Lift it out. Reverse it 180^{o} and reinsert it.

LINE CORD ATTACHMENT

The instrument comes equipped with a special line cord, designed to engage a molded recess in the rear panel. It is recommended that it be fastened to the case to prevent loss. A clip and screw provided with the line cord permits securing it to the rear of the case, using the threaded insert adjacent to the power line connector. Extra line cord assemblies are available from the factory under Part No. 274570-001.

SECTION 4

OERATION

FRONT PANEL DESCRIPTION
(See Figure 4-1)

1. Display: 4-1/2 digit LED display.
2. Input Jacks: Positive input jack holds an input protection fuse for the current mode. It can be removed for replacement by using one of the knurled thumb screws at the rear as a wrench.
3. Annunciator: Single LED lamps to display the dimensions of the variable being measured.
4. Mode Switch: 6 position mode switch for the functions indicated. The RF probe position is applicable only when using an RF probe accessory. Stops are built into the switching mechanism.

CAUTION

Do not attempt to rotate the mode switch beyond the designated limits.

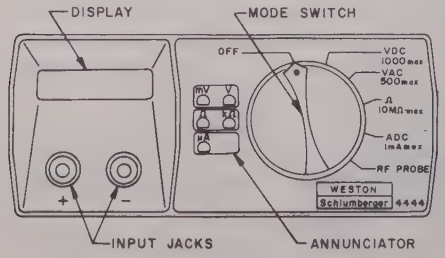


Figure 4-1. Front Panel

REAR PANEL DESCRIPTION
(See Figure 4-2)

1. Power line connector.
2. Line voltage indicator.
3. Full scale calibrate adjustments: Used when calibrating ±1 volt DC range.
4. Pin jacks for interconnection to optional accessories: These are wired in parallel with the input jacks. They may also be used for rear access to the instrument in the event of panel mounting.
5. Mounting Inserts: These are used for mounting the Model 4444 to any one of a number of accessories which are intended to accompany this basic multimeter. The insert next to the power-line plug may also be used to retain the line cord as noted previously.
6. Line Fuse: This is mounted in a fuse clip just inside the rear panel and is accessed as described under line voltage selection.
7. Removable Slide: For access to card-edge connector when operating with battery pack accessory.

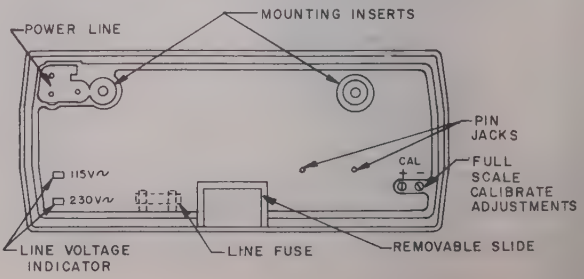


Figure 4-2. Rear Panel

RIGHT SIDE
(See Figure 4-3)

The designated hole permits access to a DC zero adjustment (RV7, board 1) in the chopper amplifier. It may be used to achieve optimum setting of ZERO in the DC volts mode or to compensate for offsets during the 30 minute warm-up period, or due to ambient temperature variations.

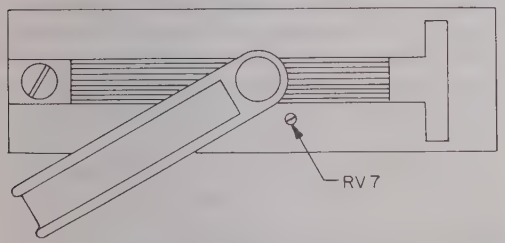


Figure 4-3. Right Side View

PRELIMINARY ADJUSTMENTS

Because of local differences in temperature between the factory and the area where the instrument will be used, it may be desirable to calibrate the Model 4444 at local ambient rather than to allow for or accept the small additional errors due to temperature coefficient. To achieve optimum calibration before use, carry out the following adjustments:

1. Set MODE switch to OFF.
2. Plug in LINE CORD firmly.
3. Set MODE switch to VDC. Display should light up along with the mV indicator.
4. With input shorted, display should settle down to within 1 count of zero within 30 minutes.
5. Apply a known positive voltage of about 1 volt. Adjust CAL + potentiometer (rear panel) for a comparable reading.
6. Reverse input leads and adjust CAL – in the same way.
7. To achieve optimum zero setting, apply ± DC voltages of about 100 microvolts and adjust side-panel zero control for equal display magnitudes. Alternately, adjust for a flickering "-" sign with input shorted. This step will optimize accuracies at 1/10 and 1/100 of full scale on the lowest VDC range.

DC VOLTAGE MEASUREMENT

All measurements are direct reading in millivolts or volts with a "-" polarity sign for negative voltages. Because of the auto-ranging feature, no further settings are required other than the mode switch.

It is recommended that the test leads not be connected to any signal source while indexing the mode switch, to prevent overload levels from being applied inadvertently during the transition.

If the input leads are left open-circuited, the instrument will display some non-zero and variable readings due to the small (less than 0.2nA) input current appearing across the high input impedance of the preamplifier. If this is objectionable, short the input leads when not in use.

CAUTION

Do not operate the meter with more than 500 volts common mode or damage to the instrument may result. Many commercial isolated power supplies if left ungrounded are capable of producing excessive common mode voltages particularly when switching polarities. To eliminate this possibility during high voltage measurement, one output terminal of the power supply or calibrator should be connected to line neutral, (3rd wire) and the terminal voltage should have reached steady state value before the Model 4444 test leads are connected.

AC VOLTAGE MEASUREMENT

1. All measurements are direct reading in millivolts or volts.
2. With test leads open-circuited, a small variable reading may be noted due to pick up. If this is objectionable, short the input test leads when not in use.
3. Be sure to observe the 700V RMS maximum limit on applied voltage. Higher voltages may induce internal instrument breakdown.
4. When measuring AC voltages, distorted sine waves can be a source of error. This instrument, operating as it does on the average sensing mode, has been calibrated on a pure sine wave. Typical 3rd harmonic distortion levels will introduce errors as much as 1/3% for each percent of harmonic distortion present.

RESISTANCE MEASUREMENT

1. All measurements are direct reading in kilohms or ohms.
2. The maximum current sent through the unknown resistor is 100 microamperes, on the 1kΩ, 10kΩ, and 100kΩ ranges. Higher ranges receive one microampere.
3. The resistance mode is protected by resistive dissipation to 200 volts peak or DC. Observe this limit. Higher voltages may damage the instrument.
4. When measuring high resistances such as 1 megohm to 10 megohms, hand capacity and pickup can introduce errors or reading variability. If in doubt, allow readings to settle and observe care in length and positioning of leads.

DC CURRENT MEASUREMENT

1. All measurements are direct reading in microamperes.
2. To check accuracy at zero, remove the test leads and allow the input to remain open.
3. Observe the 25 volt or 50mA limit for maximum input. The instrument will indicate outrange beyond 1.0999mA. In the overrange region the instrument is protected by a 470 ohms input limiting resistor and protective diodes and by a 50mA fuse. Excessive input voltages will be buffered by the resistor up to 25 volts at which point 53mA will be passing through the input fuse. Higher voltages will cause the 50mA input fuse to blow. When replacing this fuse, which is English standard, a domestic 8AG, 1/32 AMP instrument fuse may be used. The current limit will then be 1/32 AMP and the voltage limit ±15 volts.

SECTION 5

THEORY OF OPERATION

INTRODUCTION

This section presents the design and operating principles of the Model 4444 Auto-Ranging Multimeter. The theory of operation is presented at the functional level immediately below and in greater detail in the paragraphs following. Schematic diagrams and assembly and parts reference information are included in Section 7.

The instrument incorporates all circuitry needed to measure DC voltage and current, AC voltage, and resistance. The basic measuring circuit is a bi-polar analog to digital converter operating on the triple-slope principle. Triple-slope, an extension of the well-known dual-slope conversion technique, has been found to be particularly well-suited to auto-ranging applications, providing speedy range-switching and rapid settling while retaining all of the advantages for which dual-slope has become known.

The A/D converter operates on bi-polar DC voltages having full scale values of 100mV, 1V and 10V. Displays extend to 10000 counts with an overrange to 10999. Upranging occurs at 11000 counts. Beyond 11 volts the logic engages a relay to switch in an additional 100:1 attenuator to provide two more auto-ranges up to 1000 volts. Down ranging takes place below a count of 1000. The display is accompanied by automatically positioned decimal points, a "-" sign for negative DC voltages and currents, and automatic annunciation of measurement units (i.e., mV, V, Ω, kΩ, μA).

Preceding the A/D converter is a chopper stabilized amplifier, connected to provide very low input offsets, low input bias current, very high input impedance and common mode rejection. It is used with a variety of signal conditioning circuits under control of the rotary function selector switch to convert all input variables to a DC voltage for measurement and display by the triple-slope conversion system.

Rather than present the complete system diagram in the text, with all of its switching complexity, we have elected to present the functional blocks, one sub-circuit at a time, indicating the required signal interfaces. Interconnection information is presented in the schematic diagrams in Section 7 and the interested reader will be better equipped to follow it after first digesting the operating theory of the functional parts that follow.

We have started with the A/D converter, that circuit being basic to all other modes.

DUAL-SLOPE

Theory of the triple-slope converter is best approached by first reviewing the popular dual-slope converter. Figure 5-1 shows the dual-slope conversions and waveforms.

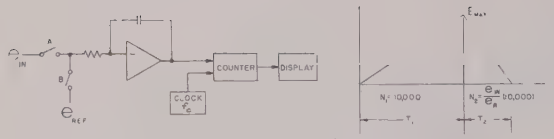


Figure 5-1. Dual-Slope Conversion

Initially, switch A is closed and B is open. An unknown voltage is integrated for a fixed period of time T_1 during which the integrator ramps up to a voltage E_{max}, given by:

$$E_{max} = \frac{e_{in} T_1}{RC}$$

At the end of T_1 A is opened and B is closed so that an opposite polarity e_{ref} is switched in. The integrator then ramps back to zero in time T_2 such that

$$\frac{e_{ref} T_2}{RC} = \frac{e_{in} T_1}{RC}$$

from which

$$T_2 = \frac{E_{in} T_1}{e_{ref}}$$

For example, if e_{ref} is made 10 volts and T_1 is made to last for 10000 pulses, then the count during ramp down N_2 will be:

$$N_2 = f_c T_2 = f_c \frac{e_{in}}{10} \times \frac{10000}{f_c} = 1000\, e_{in} \text{ volts}$$

and a 10 volt signal will give a reading of 10000 counts. Similarly, an arbitrary input X will give readings of $\frac{X}{10}$ (10000) counts.

Note that neither RC nor f_c enter into the final calculation. Since both are unchanged throughout the cycle, they cancel out. Further, by making T_1 equal to an integral number of power-line cycles, series mode rejection of power line interferences is sharply reduced. It is these features which have made dual-slope conversion as popular as it is.

Progression from dual-slope conversion to triple-slope was motivated by the special advantage it offers to an auto-ranging design. This advantage will be more manifest when considering what is required to change ranges and to do so automatically.

RANGING

Changing of ranges is often accomplished in digital multimeters by switching of attenuators or preamplifier gain ahead of the A/D converter. This permits operation of the converter at a fixed and maximum dynamic range so as to minimize linearity, drift, and noise errors.

Whether range changing is done manually or automatically, however, this approach requires close control of resistor tolerance and matching and gets progressively more expensive as the number of ranges increases.

A preferred alternative, which still permits operation over a maximum dynamic range, can be implemented by switching integrating time constant in the A/D converter.

To see how this is done in the Model 4444, consider first a dual slope system with the following parameters:

RC product: 100 milliseconds
Ramp-up time T_1: 100 milliseconds
Clock rate f_C: 100kHz
Reference voltage: -10 volts

With an input voltage of +10 volts, the integrator ramps up at 100 volts per second to a maximum of 10 volts during T_1. The input is then replaced by a -10 volt reference and the integrator ramps down to zero in 100 milliseconds, during which 10000 clock pulses are counted. The final count is 10000 corresponding to 10.000 volts full scale.

Switching to a lower range, e.g., 100 millivolts FC is accomplished by changing RC from 100 milliseconds (1 Megohm x 0.1μF) to 1 millisecond (10 kilohm x 0.1μF). With an input of 100 millivolt the integrator ramps up at 100 volts per second to a maximum of 10 volts during T_1. The dynamic range is thus preserved.

However, at the end of 100 milliseconds, when the signal is replaced by the -10 volt reference, the integrator ramps back to zero in only 1 millisecond producing only a 100 count display. Since a full count of 10000 is required for all ranges, some means of increasing the available resolution is needed.

Higher clock rates are expensive and unpractical. Triple slope conversion offers the improved resolution with no increase in clock rate or decrease in conversion speed. In the Model 4444 a resolution of 6 digits is provided so that at least 4 digits are always available for readout.

The improved resolution is secured by splitting the down ramp of the integrator into two phases, the first under control of the ±10 volt reference, and the second a 100 millivolt reference. During phase 1, the integrator ramps down rapidly and each clock pulse is counted as 100 digits. A count accurate to the next higher 100 is therefore obtained when crossing zero. The reference is then shifted to 100 millivolts of the opposite polarity and, in a subtractive mode, each clock pulse is counted as 1 digit during which residual errors in the coarse count are corrected. The effect is a greater economy in the use of clock pulses, making possible the increased resolution, with no increase in clock rate or decrease in conversion speed.

Note also, that the resistors used in range changing need not be precise or in accurate ratios of 100:10:1. Since the same resistor is used throughout the conversion cycle, its numerical value cancels out, just as in a dual-slope system.

A/D CONVERTER – SYSTEM OPERATION

The detailed implementation of the triple-slope converter in the Model 4444 is explained with the aid of Figure 5-2, Functional Diagram, and Figure 5-3, Waveforms. Figure 5-2 shows only the major functional components needed for the conversion process, all other circuitry being supportive requirements. Heart of the converter is an integrated circuit (IC) providing all count and control functions. An integrator chain integrates the input voltage and the two reference voltages under control of the IC, and transfers both signal polarity and zero crossing time to the IC. A time-shared LED display is driven automatically by the IC except for a brief blanking period during the drift correct period for updating the display store. Master clock for the system is a 101kHz crystal-controlled 2-phase oscillator. All switches in the integrator chain are either J FETS or MOS FETS driven by driver circuitry not detailed in Figure 5-2.

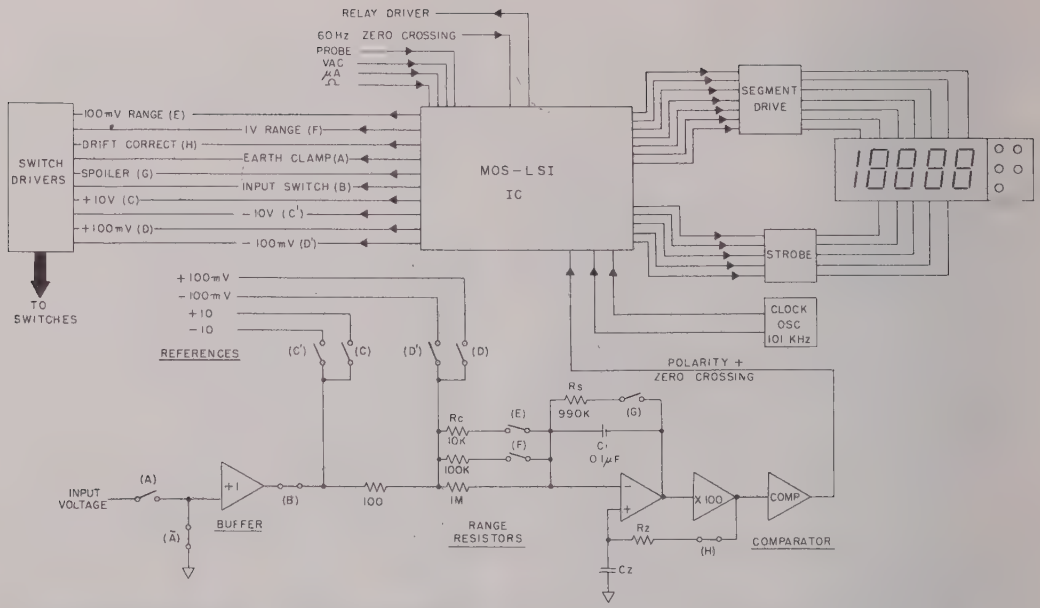


Figure 5-2. Triple-Slope Converter Functional Diagram

A/D Conversion Cycle

Let us examine the integrator chain more closely, tracing its operation in response to a hypothetical +3.45678 volt input. Refer to Figure 5-3, Waveforms. The conversion cycle is continuous and repetitive but will be assumed to start with the negative crossing of the 60Hz power line waveform. The succeeding steps are as follows:

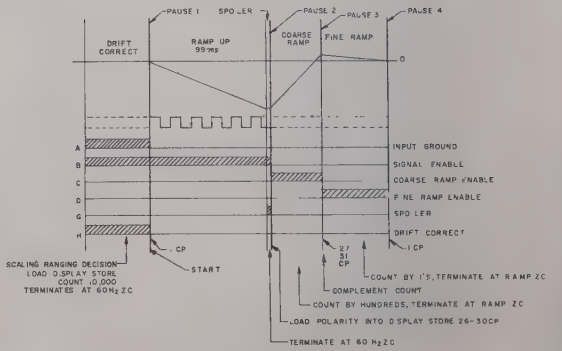


Figure 5-3. Triple-Slope Converter Waveforms

1. Pause 1 — 1 clock pulse in duration. This delay is required for proper internal functioning of the IC. A is open, $\overline{A}$ and B are closed applying ZERO to the integrator.
2. Ramp Up — 10000 clock pulses (99 milliseconds) long. During this interval A and B are closed, $\overline{A}$ open, applying the input signal and causing the integrator to ramp down. Switches E and F which control sensitivity are assumed open so that the ramp rate is about (3.5V/1MΩ)X0.1μF) = 35 volts/second. The integrator will reach about -3.5 volts in 99 milliseconds.
3. Spoiler — During this interval, switch G closes so that although the input is still applied, the integrator's fall is halted. (The purpose of this step is to improve normal mode rejection and will be analyzed more fully under Spoiler Operation). Inputs remain connected through switches A and B until the next negative zero crossing of the 60Hz power line which initiates step 4.
4. Pause 2 — This lasts between 26 and 30 clock pulses during which the input signal is grounded and the integrator output remains steady. The polarity of the integrator output and hence of the signal is detected by IC during this interval to determine which reference voltages will be subsequently applied, and to store polarity information for subsequent transfer to the display.
5. Coarse Ramp — During "Coarse Ramp," switches A and B are open, and $\overline{A}$ and C are closed applying a —10 volt reference. The integrator ramps back toward zero at 100 volts/second. The counter chain in the IC will have started at a count of zero and will count each clock pulse as 100 counts during this step. Since the voltage is 3.45678 volts, it takes between 3456 and 3457 clock pulses to cross zero, an event which is detected by the comparator and passed onto the IC. The ramp will continue until the first clock pulse after zero crossing. The ramp is then terminated by opening switch C. The count remaining on the IC at this time will be 345700 since the system had been counting by hundreds. The overshoot beyond 345678 is 22 counts which must be subtracted to produce desired count of 345678.
6. Pause 3 — This lasts from 27 to 31 clock pulses and serves to complement the count in the 6 decade register with respect to 999999. The complemented count is 654299. Note that subtraction can be achieved by complimenting and adding.
7. Fine Ramp — During this step, switch D is closed applying a +100mV reference. The integrator ramps back to zero at 1 volt/second. Since the integrator had overshot zero for 22 microseconds at 100 volts/second, a residue of +2.2 millivolt remains. At the new discharge rate of 1 volt/second, the integrator takes 2.2 milliseconds to reach zero, during which 22 clock pulses are counted. The count is thus brought to 654321 which is internally recomplemented to yield 345678.
8. Pause 4 — One clock pulse long — no inputs applied.
9. Drift Correct Period — This final phase has several purposes. First, the final 6 digit stored number is examined and the four most significant figures are transferred to a display store. In this case, the display would read 3456. In the event of a final count 003456, the same four digits would be transferred but decimal point position and annunciation would be altered to provide a display of 34.56mV instead of 3.456V. (If a number greater than 10999 had been reached, transfer to display is inhibited and the previous display continues.)

The six-digit number is also examined to determine if a range change is required. If so, switches E or F or the relay are engaged to change the sensitivity of the system for the next conversion cycle.

During all of step 9, the input to the integrator is maintained at zero by closing B and $\overline{A}$ and opening A. The effect of any offsets present due to the unity gain buffer or intrinsic to the integrating operational amplifier are fed back through closed switch H to set up a corrective bias on capacitor Cz. This phase lasts for 10000 clock pulses in addition to the time taken for scaling and loading the display, thus ensuring adequate time for the corrective bias to be set up on Cz. This bias will maintain itself for the remainder of the succeeding cycle and will be refreshed during the next drift correct period.

Auto-Ranging

During the drift correct period, the 6 digit final count is examined to determine if a range change is needed. The examination takes the form of a search for leading zeros or overflow beyond 10999.

For example, the application of 3.45678 volts when the sensitivity is set at 10 volts (R_{in} = 1 megohm) gives rise to a count of 345678 in the 6 digit register. No change is required since the best dynamic range of the integrator is being used.

A sudden change to 345.678 millivolts will result in a 6 digit count of 034567, (or 34.5678 millivolts to a count of 003456). The presence of one or two leading zeros causes a shift of one or two places to the left before entering the display store so that only significant data is shown. At the same time, switches F or E respectively are closed so that the subsequent conversion will make use of the full dynamic range of the integrator.

Because the interim counts were obtained at inadequate dynamic range, the last 1 or 2 digits may be in error. However, the reading is transient and recovers to rated accuracy in succeeding conversion cycles. In the interim, a useful display is obtained and the user is not disturbed by an extended inhibit or blanking operation characteristic of previous auto-ranging instruments.

If while set to maximum sensitivity, i.e., 100mV (R_{in} = 10k ohm), an input larger than 1099mV but less than 11 volts is applied, the converter will inhibit one data transfer and will up range to the 10 volt range after which it will display. It will either remain at the 10 volt range or down range once more to the 1 volt range, depending on the actual level. If an input above 11 volts is suddenly applied, the converter will up range to 10 volts and then to 1000 volts after which it will display and either remain at 1000 volts or down range to 100 volts. No more than 2 conversion intervals can be lost due to ranging.

Spoiler Operation

It has been pointed out that the spoiler interval and switch G functioned to improve Normal Mode Rejection Ratio. This operation will now be explained in more detail.

Rejection of line frequency interference riding on top of an unknown DC has generally been handled in integrating converters by making the integration time an integral number of line frequency periods in length. Thus, exactly 100 millisecond integration time (during which signal is applied) will permit perfect rejection of line frequencies of exactly 50Hz and exactly 60Hz (5 periods and 6 periods, respectively) since the contributions of positive and negative halves of the interference exactly cancel. In the Model 4444, some latitude is given to the local line frequency with no reduction in rejection over a ±1% frequency range.

By making the clock frequency 101kHz, and starting the coarse ramp at the zero crossing of the AC line, the 10000 pulses taken for the coarse ramp terminate in 99mS. This is between zero and one millisecond before the next zero crossing of the AC line, depending on the exact value of the line frequency.

The only impedance in the integrator feedback loop during the coarse ramp is C_1 integrating both the DC or signal component as well as 50Hz or 60Hz interference. When, at the count of 10000, switch G is closed, the rate of rise for DC is spoiled, but the impedance is essentially the same for 50Hz or 60Hz due to the overriding contribution of the capacitor. Hence, line frequency interference continues to be integrated until the next zero crossing, when both DC signal and interference are disconnected.

The line frequency is thus integrated for an integral number of AC line cycles even if the system clock is not synchronous with or locked to the line, and rejection is maintained high.

The reason that the integrator does not continue to rise due to the DC component of input signal can be seen by noting that the output voltage at the end of 99 milliseconds will be given by

$$\frac{-e_{in}\ (0.099)}{R_{in}C}$$

Whereas the voltage which would be reached asymptotically if Rs had always been in the circuit is given by

$$\frac{-e_{in}}{R_{in}} \times Rs$$

If we make RsC = 0.099 seconds, the two expressions are equal and the integrator output after 99 milliseconds will already be at its final state and thus move no further. Since Rs is 990k ohms and C = 0.1μF, this condition is fulfilled.

A/D CONVERTER — CIRCUIT DETAILS

Integrated Circuit — a 40 pin MOS/LSI integrated circuit. It has the following inputs:

1:	+12 volts
21:	-17 volts
29:	Common
19,20:	101kHz two phase clock, swinging between +12V and -17V
9:	AC line zero crossing, +12V to -17V
8:	Comparator input detects polarity and polarity change at output of integrator chain, +12V to -17V swing
4,5,39,40:	Directs IC into appropriate mode of operation as controlled by mode switch, i.e., RF Probe, VAC, Ohm, μA respectively. Absence of -17V on any of the four lines signifies the VDC mode.

In addition, there are the following control outputs, where "enabling" is generated by -17 volts, Logic "1"

2: 100mV range: "1" state closes switch E through on FET driver circuit

3: 1V range: closes switch F

11: Drift Correct: closes switch H during Drift Correct interval

12: Input clamp: closes $\overline{A}$ and opens A where input is to be grounded

13: Spoiler: closes switch G during Spoiler period

14,15,16,17: Reference control: closes switches C, C', D, D'

18: Signal Control: closes switch B except during coarse and fine ramps

38: Relay control: 0 to 6 volts, closes relay for 100, 10000VDC; 10, 100, 700VAC; 1 megohm, 10 megohm ranges

The integrated circuit also has the following display control outputs:

24-28: Display strobe Control: 0 to 1.5 volts; each terminal successively energized with a duty cycle of 200 microseconds on and one millisecond off.

30-37: Display Element Control: Swings between 0 and 6 volts, provides appropriate combination of levels to enable 7-segment numerals 0 through 9, decimal points, and annunciator lamps, in synchronism with the strobe control.

Integrator Chain

The integrator chain includes a unity gain buffer, a FET input integrator and two stages of gain for drift control and for zero crossing detection.

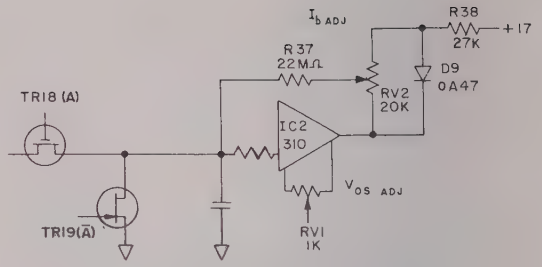


Figure 5-4. Input Buffer Circuit

In Figure 5-4, IC2, is the unity gain buffer which serves to transform impedance between the signal conditioning stages and the integrator. TR18 and TR19 are driven by a separate FET driver circuit which interfaces with control IC. RV1 adjusts IC2 for minimum voltage offset. The network of R37, R38, RV2, and D9 cancels out the input bias current of IC2. This minimizes the impact of changing source impedance (with mode change) on the offset generated by IC2 and thereby simplifies the drift correct circuitry. Note that R37 is bootstrapped to the buffer's output so that input level changes do not change the level of injected compensating current. D9 is a germanium diode having a TC which matches the bias current TC of IC2.

The integrator and drift correct loop are shown in Figure 5-5. Action of the Switch Drivers during the conversion process will be described in subsequent paragraphs under Switch Drivers.

Resistor R39 is included to equalize the impedance seen by the integrator circuit. The 10 volt references and the buffer drive from essentially zero ohms but

the 100mV references from 100 ohms. The equalization insures that the RC product remains constant over the conversion cycle.

The integrating amplifier is a composite of a fast LM301A and a dual FET buffer designed to minimize leakage of charge off capacitor Cz.

During the drift correct phase, the voltage applied to the integrator is reduced to the residual output of the buffer after its effects have been trimmed. Additional errors during this phase include offsets at the input of the dual FET preamp and those reflected to the FET input from IC3. All of these errors act to create a residual error — ramp which is amplified by 100 in IC6 and fed back as a correction voltage across Cz. The loop will stabilize during the drift correct period. The correction voltage will hold for the remainder of the cycle since Cz is a low loss capacitor and the dual FET imposes low leakage.

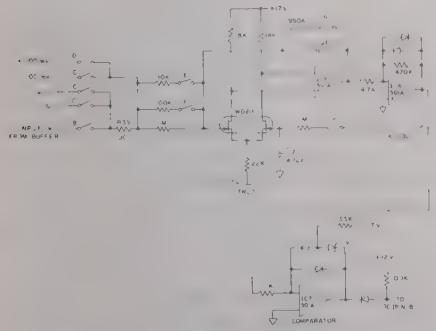


Figure 5-5. Integrator Chain

Signal polarity from input through to the output of IC6 is maintained with no inversion. IC7 is a wide band amplifier operating open-loop, but with diode clamping networks designed to permit rapid recovery by preventing saturation. The output of the amplifier will swing between -0.6 and +13 volts. The waveform applied to the MOS IC will swing between 0 and +12 volts. A positive signal at the input of the integrator chain will give rise to a negative peak signal at the comparator output and will be interpreted as a negative instrument input signal because the common amplifier inverts.

Display

The display circuit centers on a time-shared, 4 digit plus "1", 7-segment display LED synthesized on a single substrate. The configuration is illustrated in Figure 5-6. Each linear segment is an LED. Cathodes of all segments in a given digit are connected in common and returned to ground under control of one of 5 MPS-A13 transistors.

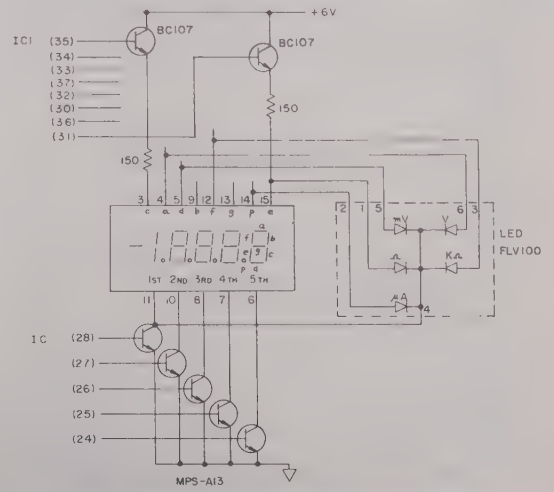


Figure 5-6. Display and Drivers Diagram

These are strobed sequentially under control of the MOS IC. The annunciator display is connected in common with digit No. 1 and is therefore strobed at the same time. Choice of segments to be illuminated in each digit is under control of switching transistors (7 elements plus 1 decimal point), in turn driven by the MOS IC.

Clock Oscillator

A two phase clock oscillator provides a 101kHz pulse train to the master IC. The circuit, shown in Figure 5-7 contains a transistor oscillator stabilized to ±0.1% with a ceramic crystal at 404kHz, a two flip flop divider chain and level shifting circuitry. The waveforms, shown in Figure 5-8, are structured to prevent race conditions. Output levels swing between -17V and +12V. Note that the ICs in the clock circuit straddle -12V to -17V to obtain their 5V operating supply.

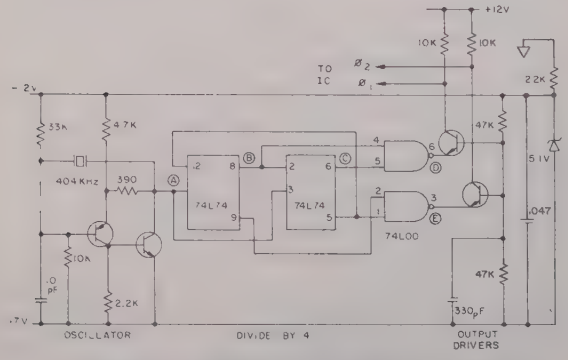


Figure 5-7. 101kHz Clock Oscillator Circuit

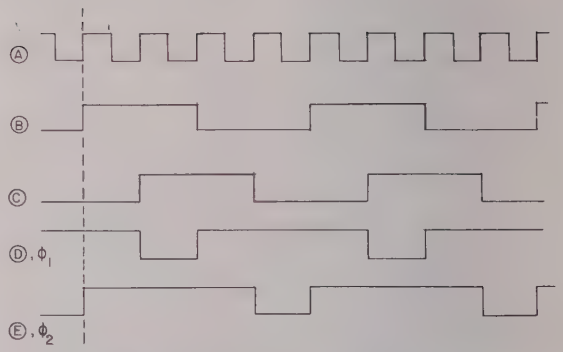


Figure 5-8. Clock Oscillator Waveforms

Reference Voltage Generator

A set of stable reference voltages is provided by the circuit shown in Figure 5-9. A reference diode 1N4577 provides a 6.4 volt reference at ±20 ppm/°C. Current through it is stabilized at the optimum operating current of 2mA by the 10 volt output of the operational amp which it drives, thus providing its own regulated current. A variable resistor RV5 and selectable resistors in the feedback path permit trimming the amplifier gain to accommodate tolerances in the diode and in the feedback resistors. The diode is provided to prevent latch-up during turn on.

Amplifier offset errors are negligible compared to 6.4 volts, thus ensuring a stable 10 volt source. The 100mV source is not as critical, since each 1% error in the 100mV reference counts for only .01% in the final answer, and is easily provided by untrimmed 1/4%, 100ppm metal film resistors.

Negative references are derived from the +10 volt source by an inverter trimmed to precisely unity gain by RV6 and further divided down for the -100mV source.

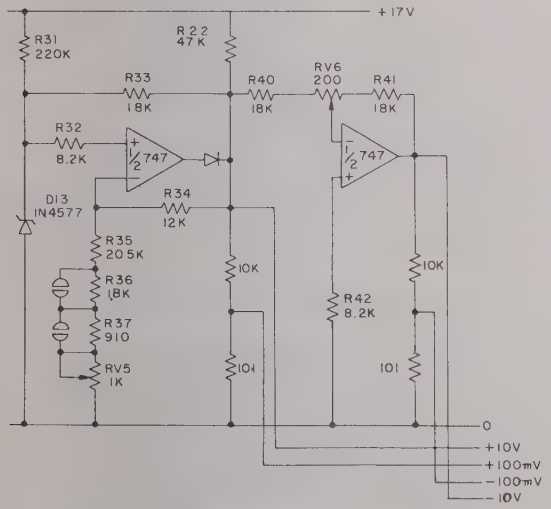


Figure 5-9. Reference Generator Circuit

Switch Drivers

1. Input Clamp Drive Circuitry
   Switches A and $\overline{A}$ are driven by the interface circuit shown in Figure 5-10. In the PASS condition TR1 is turned on by +12V from MOS IC. A and B fall to -17 volts. The 2N4303, being an N channel J FET is turned off by the high negative gate bias. The 3N163, a P channel MOS FET is turned on since its gate is at least 7 volts more negative than any applied signal. In the CLAMP condition, the driver input is open, TR1 is turned off and the voltages A and B rise to +12V and zero respectively. The 2N4303 is turned fully on clamping the buffer input to ground. The 3N163 is biased to cut off, its gate being more positive than any E_{in}. The diode prevents voltage B from rising above 0 volts which would bias 2N4303 into a forbidden enhancement region.

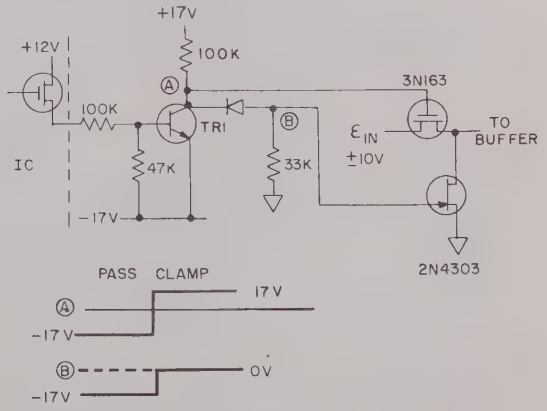


Figure 5-10. Input Clamp Drive Circuit

2. Drivers for Signal Input B and Coarse References (C, C^1) (Ref Figure 5-11)
   These circuits are identical in their need for very fast switching so as to define the intervals when signal and reference are being applied to better than 1/100 clock pulse period (0.1 ms). Remem-

ber that each clock pulse counts for 100 counts during coarse ramp. The circuit uses symmetrical drive transistors for turn on and shut off and capacitor peaking for speed up. During PASS, the upper transistor is turned ON and the gate and drain are at the same potential, insuring ON. During BLOCK, the lower transistor is ON and the gate is at -17 volts, therefore more negative than any E_{in}. The switching FETS are U1899E, all matched up to within one ohm, of each other in the ON state, to insure that the RC product remains essentially constant throughout the conversion cycle.

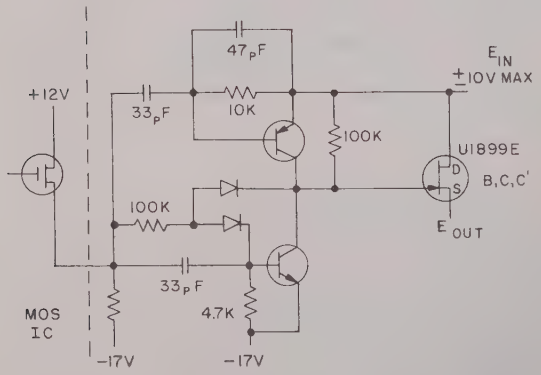


Figure 5-11. Signal or Coarse Reference FET Drive Circuit

3. Low Level FET Drivers (Switches D)
   These drivers operate in the same way as those in Figure 5-11, except that there is no speed up circuitry. See Figure 5-12.

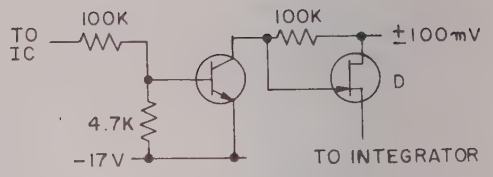


Figure 5-12. Low Level FET Driver Circuit

4. Gain Control Driver (Switches E, F)
   The bipolar circuit of Figure 5-13 generates a potential which swings between 0V and -17V. The 0V state insures full turn on, and the -17V state provides turn off.

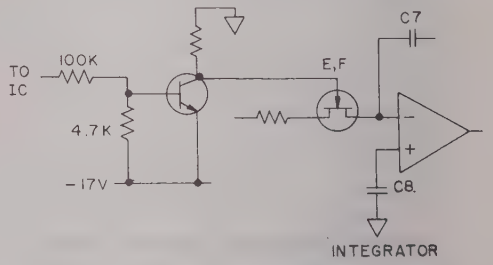


Figure 5-13. Gain Control Driver Circuit

5. Spoiler Drive (Switch G)
   The spoiler drive circuit and Switch G, a 2N4303, is shown in Figure 5-14. An enabling signal of -17V at the driver input permits the gate to rise to the drain potential insuring turn ON. Application of +12V turns on the driver transistor returning the gate to -17V and insuring cutoff.

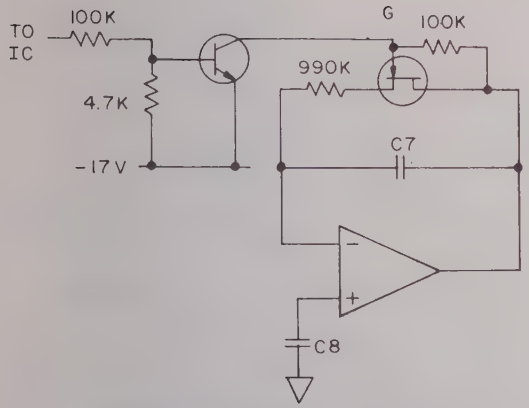


Figure 5-14. Spoiler Drive Circuit

6. Drift Correct Driver (Switch H)
The drift correct control circuit applies either +12V or -17V to the gate of MOS FET TR25, a 3N163, as shown in Figure 5-15. At -17V, the 3N163 is turned on transferring the error voltage from the output of IC6 to the 4.7μF storage capacitor. The additional series RC network is included to desensitize the feedback loop to power supply ripple which might be picked up.

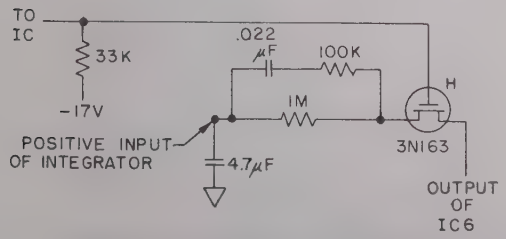


Figure 5-15. Drift Correct Circuit

SIGNAL CONDITIONING CIRCUIT

This circuitry has the task of converting all input measurands to a DC voltage in the range of ±10 volts, maximum. Common to all operating modes is a chopper stabilized DC amplifier. It is connected in a variety of ways, depending on the operating mode, to provide high input impedance, a virtual ground, or high AC gain to support the operational AC to DC converter. Subsequent paragraphs will show how each operating mode is implemented.

DC Voltage Mode

The input circuit configuration for the DC volts mode is shown in Figure 5-16. Switch terminal designations are included to assist the reader in relating the circuit to the schematic diagram shown in Section 7.

The chopper amplifier is operated in the follower mode which porovides very close to unity gain, low output impedance and high input impedance. In addition, points A and B are essentially at the same potential.

R19 is included to isolate the amplifier output from stray capacities to line neutral, which would promote oscillation. C26 provides some additional input filtering and also minimizes the runaway behavior due to random amplifier input current which would create erratic readings when the input is open circuited. R52 and C1 are for relay contact protection.

With the relay in the position shown, the amplifier input is merely isolated from the + input terminal by

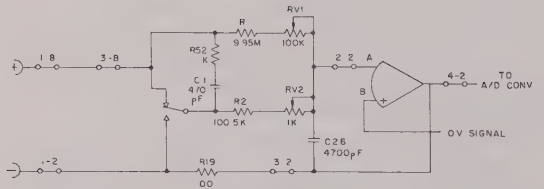


Figure 5-16. DC Volts Input Circuit

101 kilohms. Since input bias current is less than 0.2nA over the allowable operating temperature range, the offsets produced are only 20 microvolts and are zeroed out during set-up.

In the opposite relay position, and attenuation of 1/100 is introduced. The two resistor networks are each adjustable because they are used for Resistance Mode Calibration as well as for DCV attenuation.

Amplifier output voltage is limited to ±12 VDC and the gain is almost identically equal to "-1". Signal levels up to ±10.999 volts will be accepted in the unattenuated position. Signals of 100V FS and 1000V FS will be attenuated to 1V FS and 10V FS respectively by relay action.

Resistance Mode

The input circuit configuration for the Resistance Mode is shown in Figure 5-17. Point A is maintained as a virtual ground by the amplifier configuration. Therefore, the current Is flowing from the +10V source through the scaling resistors, Rs, is given by 10/Rs.

On the 1k, 10k, 100k ranges, the relay is set as shown and the current produced is 10V/100kΩ = 100μA. Corresponding full scale voltages are 100mV,

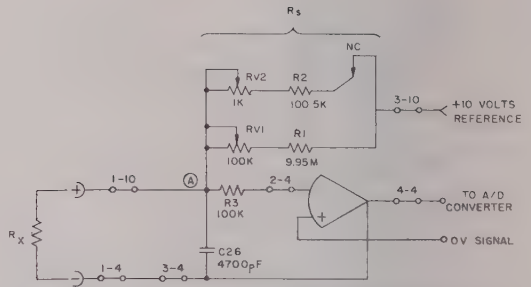


Figure 5-17. Resistance Measurement Circuit

1V, 10V. When the A/D converter signals an up-range requirement beyond 10.999V, the relay is opened and the series resistor climbs to 10MΩ, producing a 1μA source. Corresponding full scale voltages for the 1MΩ and 10MΩ ranges are 1 volt and 10 volts. The 100kΩ resistor R3 is employed for input overload protection.

DC Current Mode

In the DC current mode, the common amplifier operates as a current to voltage converter, rather than as a follower. See Figure 5-18. A 10 kilohm feedback resistor converts input current entering the summing junction A into a voltage such that 1mA produces 10 volts. The summing junction is still a virtual ground so that the only impedance seen between the input jacks is the resistance of the fuse and associated wiring. Resistance will be typically 35 ohms. The relay does not become engaged in the DC current mode.

Input currents beyond 1mA cause the amplifier to limit, in which case protective diodes at the amplifier input conduct providing a return path to the "-" in-

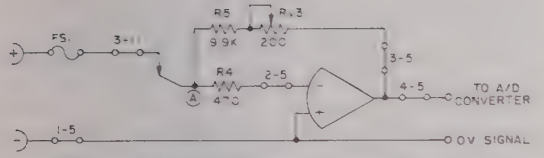


Figure 5-18. DC Current Input Circuit

put. The 470 ohm resistor provides protective current limiting up until the fuse blows.

RF Probe Mode

This operating mode is identical with the DC current mode, except that the annunciator lamp is switched from μA to mV. This mode works only in conjunction with an accessory module which converts RF voltage at 1V full scale to DC currents at 100μA, max. The converted DC output voltage is (100μA x 10kΩ) 1000mV max.

AC Voltage Mode

Conversion of AC voltage to a DC level is accomplished by an operational rectifier circuit, supported by the common chopper-stabilized amplifier. The conversion ratio is 500mV DC per 1V RMS input, and the transformation is average sensing, RMS calibrated. The output is subsequently scaled up by a factor of 2 (in the VAC mode only) in the A/D converter to make the display direct reading in volts.

The 100mV and 1V range are converted without attenuation. The 10V, 100V and 500 volt ranges are all attenuated by 1/100 before conversion and produce 50mV, 500mV and 2.5 volts DC output.

The circuit is shown first in block form, in Figure 5-19. It comprises an input network which either attenuates 1/100 or provides direct input, depending on range, a unity gain buffer for impedance transformation, an operational rectifier circuit which provides half-wave rectification with operationally sharpened diode breaks, and a low pass filter to filter out the ripple and pass only DC. The gain of the rectifier is 1.11 to scale the average value of the half-wave rectified sine wave to one-half the RMS level of the sine wave producing it.

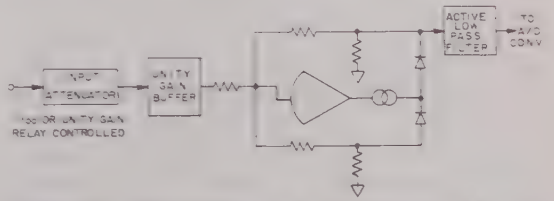


Figure 5-19. Block Diagram of AC Conversion Circuit

Figure 5-20 shows the input circuit in its two modes and the buffer. The input network of C25 and R3 or R1 plus R2 provide DC blocking and a 1 megohm input impedance. Its input time constant provides a roll off of less than .02% at 40Hz. RV1 permits adjustment to exactly 100/1. The 310 buffer is protected against overload by the limiting resistor R5 and the diode network.

The active low pass filter circuit is shown in Figure 5-21. It interfaces the operational rectifier with the A/D converter. Its cutoff frequency is 4Hz and it rolls off at 60dB per decade, so that ripple attenuation at 40Hz is of the order of 1000 to 1. Note that offsets in the amplifier are not transmitted to the A/D converter. However, the source impedance seen by the

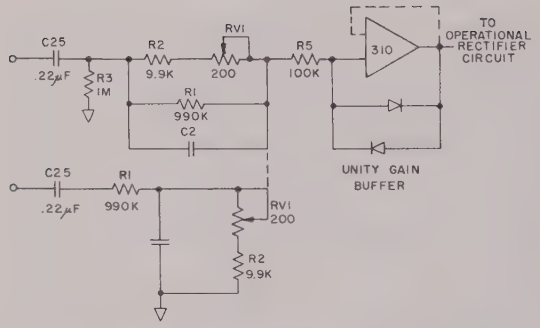


Figure 5-20. AC Converter Input Circuit

A/D converter is 44 kilohms as compared with essentially zero in other operating modes. This additional impedance has made it necessary to compensate for input bias current in the buffer stage of the A/D converter.

The operational rectifier portion of the converter circuit is shown in Figure 5-22. In its simplest form,

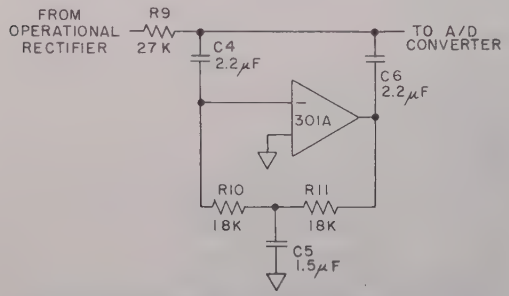


Figure 5-21. Active Low Pass Filter Circuit

the configuration is that of an inverting amplifier with polarity-selective negative feedback loops. With only minute negative input swings, the amplifier output swings positive enough to drive both upper diodes into conduction and the loop is closed through the 16.9kΩ resistor. The summing junction is held at virtual ground. The output waveform is the negative of that at the input and amplified by the adjusted ratio of feedback resistor to input resistor.

On positive input swings the upper diodes are reverse-biased. However, the lower path conducts bringing the summing junction to ground once more. The voltage passed on to the low pass filter during this half-cycle is zero since the summing junction is at ground potential and there is no current flow in the 16.9kΩ resistor. The resulting waveform is a half-wave rectified sine wave, as required.

The diodes shown are hot carrier diodes having very low shunt capacity low reverse leakage, and low forward drop, thereby minimizing errors at low levels and high frequencies. The use of two diodes in each feedback loop serves to isolate the residual reverse leakage current and shunt capacity inherent in the diodes.

Input Capacitor C3 isolates the operational rectifier from offsets in the buffer amplifier and introduces an additional roll off at 40Hz of only 0.02 to 0.03%.

Common Amplifier

All operating modes discussed thus far make use of a high gain chopper stabilized amplifier. This paragraph will describe its operation. Figure 5-23 and Figure 5-24 show the essential circuitry of this amplifier.

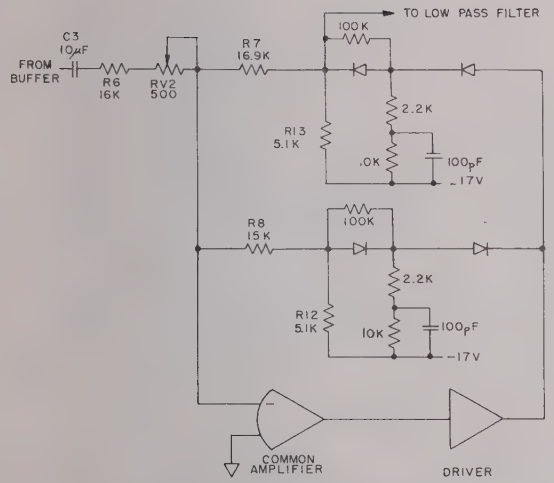


Figure 5-22. Operational Rectifier

D1 and D2 provide input protection in event of overload. Output limiting is provided by the onset of 100% negative feedback when the output voltage exceeds 12 volts in magnitude. The feedback path is through D3, D4, and D5 or D6.

DC and AC paths are split at point S. A low pass filter removes any AC components greater than 16Hz, passing the DC on to be chopped by TR1. The AC component is fed forward through C9 to be later combined with the amplified DC component in IC2. The symmetrical form of the low pass filter also prevents switching transients at TR1 from feeding back to the amplifier input and to the users circuitry.

The DC component is converted into a 400 cycle square wave by TR1 and subsequently amplified as AC eliminating susceptibility to DC offsets and drift. At TR2, the amplified square wave is demodulated, or synchronously restored, by a chopping waveform which is 180° out of phase with that at TR1, providing polarity inversion as well as restoration.

R16 and C10 filter out the 400Hz component at the output of TR2, passing pure DC on to IC2. There it is combined with the AC component and the two amplified to form a composite amplified signal.

Due to the feedback from output to input, voltage levels across D1, D2 are very small and the "+" input terminal looks like a virtual ground.

The chopper drive circuit is shown separately in Figure 5-24. The multivibrator oscillates at about 400Hz, providing two anti-phase square waves at points A and C. In addition, a small, rounded off anti-phase component is provided at B to chopper TR1 to suppress current spikes which would otherwise feedback to the amplifier input.

Power Supply

The power supply circuitry is shown in Figure 7-7. Voltages of ±17 volts are provided for analog and logic circuits, and +6 volts for the display. In addition, -6 volts is made available at the rear PC board connector to inhibit battery pack inverter action when line voltage is provided on a system using the battery pack accessory. Nominal loads on the ±17 volt and +6 volt supplies are 70mA and 250mA, respectively.

Auxiliary to the power supply are two control circuits. The first circuit, (Ref Figure 5-25) generates an

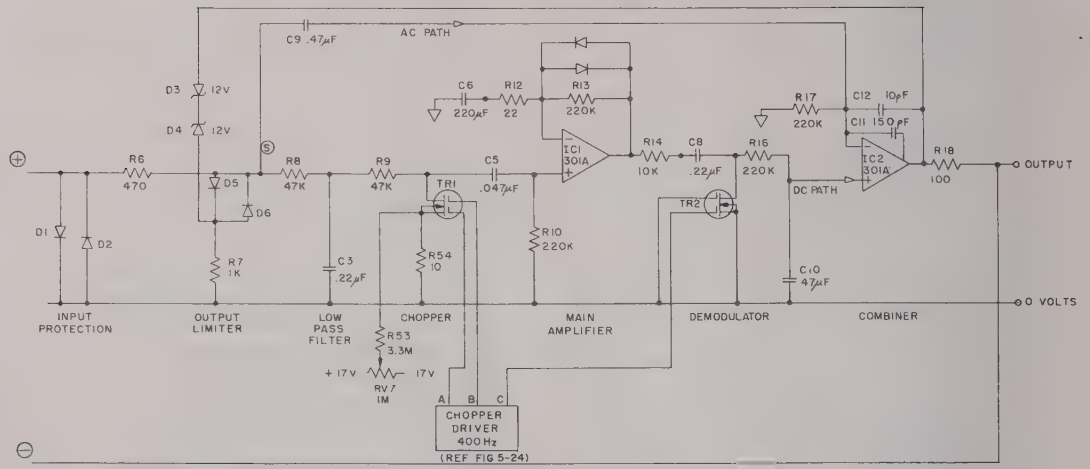


Figure 5-23. Common Amplifier Circuit

AC line zero crossing signal. An AC signal derived from the power transformer is shaped, with the aid of feedback into a square wave, switching between +12 volts and +1.2 volts.

The negative-going transition of the square wave corresponds to a positive-going transition of the sine wave, and is fed to the master IC at pin 9 to synchronize ramp action.

A second circuit using TR13, Figure 7-7, drives pin 10 of the master IC, controlling the mode of operation of the A/D conversion according to whether or not AC line voltage is available to synchronize the A/D conversion. In the presence of an AC line, -6 volts will be available to turn on TR13 and hold pin 10 at about -0.6 volts. When on battery operation, the -6 volts will not be available and pin 10 will rise to +12 volts.

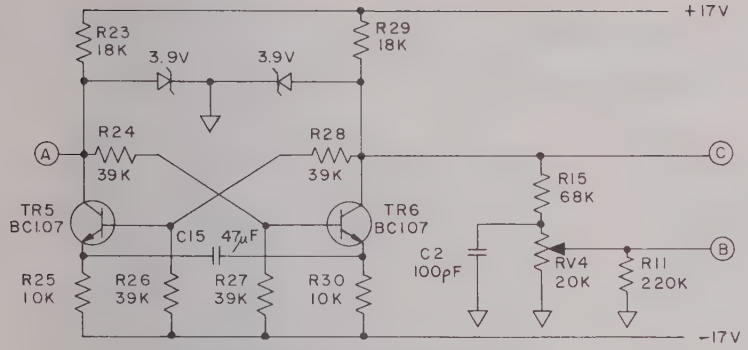


Figure 5-24. Chopper Drive Circuit

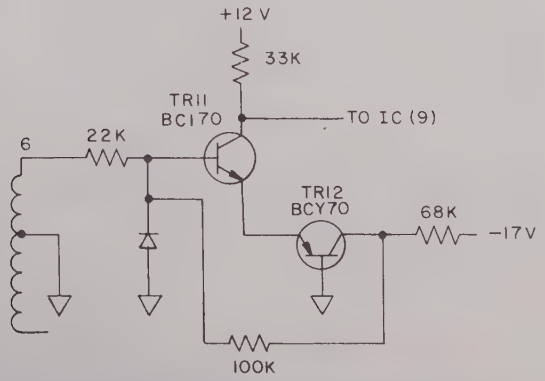


Figure 5-25. Line Zero Crossing Signal Circuit

SECTION 6

MAINTENANCE

OPERATING MAINTENANCE

In the course of normal operation, the instrument should require no maintenance other than the occasional replacement of an overload protection fuse or a line fuse. Faulty operation may often be traced to improper use. Below is a list of potential symptoms and suggested remedies.

1. Power fuse blown out. Check the setting of the 115 volt/230 volt jumper at the rear panel. If the local line voltage is 230 volts, the jumper plug should be set accordingly. If the fuse has blown, remove the rear thumb screws and swing away the rear panel. The fuse will be found in clips on the bottom board. The instrument is normally supplied with a 100mA Slo-Blow, 8AG fuse. It may be replaced by an 1/8 Amp 8 AG Littlefuse 362.125.
2. Half-bright display along with malfunction. It may be that the power supply is set for 230 volts in a 115 volt area, thus starving the instrument for power. Reverse the line-selector jumper.
3. No response on DC Amps of RF Probe. It may be that the input protection fuse behind the "+" input jack has been blown. This can easily occur if the input leads are impressed in the mA mode across full line voltage, or any source above 25 volts which can supply over 50mA. The fuse can be removed by using either of the rear thumb screws as a wrench to remove the "+" input jack. The fuse normally supplied is a 50mA Slo-Blow 8AG fuse. The input circuit will accept up to 25 volts through a 470 ohm input limiting resistor before the input current exceeds 50mA. The recommended replacement fuse is a 1/32 Amp 8AG Littlefuse 361.031. Maximum voltage will be of the order of 15 volts with this replacement.
4. Runaway or Random Display. This is a normal condition if the input is left open on either DCV or ACV, or shorted on DC Amps.

CALIBRATION

Routine

Throughout the service life of the instrument, there should be little need to readjust calibration controls. As an accommodation to those desiring the ultimate in DCV accuracy, the DC zero control and the positive and negative full scale DC voltage controls have been made accessible to the outside. The remainder have been set at the factory using a specially designed work-case to provide access.

The DC voltage specification published in this manual is guaranteed for 90 days when operated at the same temperature at which the instrument was calibrated, ($23^{o}C \pm 1^{o}C$). Deviations from this temperature can result in zero shift up to $2uV/^{o}C$ and reading errors of up to 40 $PPM/^{o}C$. To attain the

maximum DCV accuracy of which the instrument is capable, the user should recalibrate at the local ambient temperature. The procedure is as follows:

1. Set MODE switch to VDC and allow instrument to warm-up one hour minimum.
2. Apply a known positive voltage of about 1.0 volts. Adjust CAL + control (rear panel) for a comparable reading.
3. Reverse input leads and adjust CAL- control for an identical reading.
4. Adjust ZERO by applying a DC voltage of about 0.10 mV. Adjust DCV zero control (side panel) so that magnitude of reading obtained does not change when input polarity is reversed. Actual readings will probably be somewhat lower than 10 digits.
5. Repeat steps 2 and 3.

Calibration Check — DC Volts

To verify the specifications of the instrument, the following performance check is recommended. Where reference standards are required, it is important to use units of adequate accuracy and with a recalibration interval short enough to permit confidence in the results.

Test Equipment: DC Volt Standard:

Accuracy:	±0.003% Rdg
Range:	±1000 volts
Resolution:	10 microvolts

NOTES: (Ref Table 6-1)

1. Only negative voltages will have a polarity sign; absence is assumed positive.
2. Since calibration is done at ±1 volt, the ±1 volt limits should be zero. However, aging could create a drift to ± 3 counts with time.
3. When testing ±1000 volts, change voltage source slowly in 100 volt steps, allowing display to settle at each step. This is a precaution against excessively high common mode voltage transients which some calibrators can produce.

Voltage Input	*Ideal Display*	*Permitted Limits (Counts)*
Input Shorted	0.00mV	±1
±10mV	±10.00mV	±2
±100mV	±100.00mV	±4
±1 Volt	±1.000V	±3
±10 Volts	±10.000V	±3
±100 Volts	±100.00V	±4
±1000 Volts	±1000.0V	±4

Table 6-1. DC Voltage Accuracy at Reference Conditions

Inability to achieve the permitted limits on ranges up to 10 volts, when adjusted as detailed in Operating Maintenance, is a symptom of functional failure.

Inability to achieve the permitted limits on the 100 volt and 1000 volt ranges indicates a need for readjustment of the DC attenuator. See Calibration Procedure.

Calibration Check — Resistance Accuracy

Test Equipment: Resistance Standards of 100 ohms to 10 megohms in decade steps. Accuracies of 0.01% except on 10 megohms (0.025%).

Procedure: Operating Maintenance must have been performed before making this test.

NOTES: (Ref Table 6-2)

1. Test lead resistance may introduce errors at zero or other low resistances. To adequately check zero, use a short leaded jumper plug with good mating force.
2. Erratic readings may result at high resistances (1MΩ, 10MΩ) due to pick up of interference, or capacity effects. Use short leads and allow lead position and display to stabilize before reading.

In the event of failure to achieve the tabulated limits, refer to Calibration Procedure.

Calibration Check — DC Current Accuracy

Test Equipment: DC Current Calibrator with accuracy of ±.01% of reading or a combination of DC volt standard and an accurate 1 megohm resistor.

Operating Maintenance must have been performed before making this test. Currents of 1, 10, 100 microamperes and 1mA are obtainable by applying 1, 10, 100, and 1000 volts in series through a 1 megohm resistor.

Resistance Input (ohms)	*Ideal Display*	*Permitted Limits*
Short Circuit	0.0Ω	2
100	100.00Ω	±3.5
1000	1.0000kΩ	±8
10kΩ	10.000kΩ	±6
100kΩ	100.00kΩ	±6
1MΩ	1000.0kΩ	±6
10MΩ	10000kΩ	±27

Table 6-2. Resistance Accuracy at Reference Conditions

Input Current	*Ideal Reading*	*Permitted Limits (digits)*
Open Circuit	0.000μA	±1
±1μA	±1.0000μA	±3.5
±10μA	±10.000μA	±8
±100μA	±100.00μA	±6
±1mA	±1000.0μA	±6

Table 6-3. DC Current Accuracy at Reference Conditions

NOTES: (Ref Table 6-3)

1. Some instability may result due to pickup in the 1 megohm resistor.
2. Observe precaution in applying ±1000 volts to the input series network, to change the voltage slowly in 100 volt steps.

In the event of failure to meet specification, refer to Calibration Procedure.

Calibration Check — AC Voltage Accuracy

Test Equipment: AC Voltage Calibrator: accuracy ±0.02% reading ±0.002% Range ±10mV

Operating Maintenance must have been performed before making this test. (Ref Table 6-4)

In the event of failure to meet specifications, refer to Calibration Procedure.

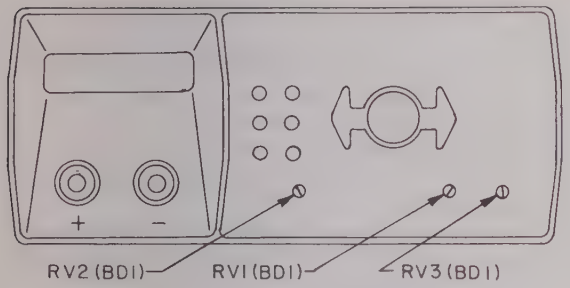
Calibration Procedure

This procedure is designed to bring an otherwise functional instrument into full compliance with the specifications and will also permit certain functional tests. Its implementation requires first an awareness of the location of every control. Figure 6-1 shows their locations and their functions. The number in parenthesis in front of each control symbol refers to the circuit board on which it is found.

All of the following tests are to be performed with the instrument either out of the case or in a work-case which makes the internal adjustments accessible. They should be performed after a warm-up of 1 hour minimum.

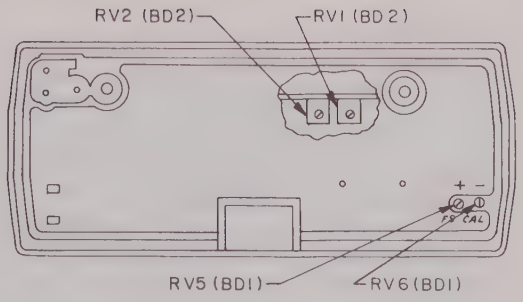
Input		*Ideal Display*	*Permitted Limits (±counts)*
Short Circuit		0.00mV	6
10mV	40Hz	10.00mV	9
	1kHz		9
	10kHz		9
100mV	40Hz	100.00mV	18
	1kHz		18
	10kHz		18
1V	40Hz	1.0000V	14.4
	1kHz		14.4
	10kHz		14.4
10V	40Hz	10.000V	27
	1kHz		27
	10kHz		27
100V	40Hz	100.00V	23.4
	1kHz		23.4
	10kHz		23.4
500V	40Hz	500.00V	13
	1kHz		13
	10kHz		13

Table 6-4. AC Voltage Accuracy at Reference Conditions

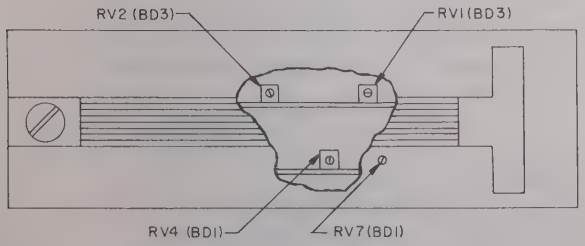


(Controls under range plate)

FRONT VIEW



REAR VIEW



LEFT SIDE VIEW

RV1 (Bd 1) = HI-Ω CAL, Part of Attenuator
RV2 (Bd 1) = LO-Ω CAL, Part of Attenuator
RV3 (Bd 1) = ADC CAL
RV4 (Bd 1) = I set Chopper Amp
RV5 (Bd 1) = + F.S. CAL
RV6 (Bd 1) = - F.S. CAL
RV7 (Bd 1) = mV Zero Set, Chopper Amp
RV1 (Bd 2) = Buffer - Vos
RV2 (Bd 2) = Buffer - I_b set
RV1 (Bd 3) = AC Atten CAL
RV2 (Bd 3) = AC Full Scale CAL

Figure 6-1. Trim Adjustments

Zero Performance

1. Set MODE switch to VDC.
2. Connect network consisting of 1M Ω in parallel with 1μF across input terminals.
3. Adjust RV4 (Bd 1) for a display of ±0.00mV.
4. Replace RC network by a short circuit.
5. Adjust RV7 (Bd 1) for ±0.00mV.
6. Reselect 'RC' and if necessary, re-adjust RV4 (Bd 1) for ±0.00mV.
7. Reselect 'SC' and check that reading is still ±0.00mV.
8. Set MODE switch to VAC and check that reading is not greater than 0.09mV.
9. Adjust RV2 (Bd 2) for 0.00mV.
10. Set MODE switch to Ω and check that reading does not exceed 0.2Ω.
11. Open circuit input terminals.
12. Set MODE switch to ADC and check that reading does not exceed ±0.001μA.
13. Zero performance calibration is now complete.

DC Voltage and Resistance Calibration

1. Set MODE switch to VDC.
2. Apply +1.0000V to input terminals.
3. Adjust RV5 (Bd 1) for 1.0000V reading.
4. Reverse input leads.
5. Adjust RV6 (Bd 1) for -1.0000V reading.
6. Reverse input leads back to normal position.
7. Increase input to +10.000V and check that reading is 10.000V ±1 digit.
8. Reverse input leads.
9. Check that reading is -10.000V ±1 digit.
10. Reverse input leads back to normal position.
11. Reduce input to +0.10mV.
12. By reversing polarity of input (reversing input leads) adjust RV7 (Bd 1) for equal readings positive and negative.
13. Increase input to +100.00mV.
14. Check that reading is 100.00mV ±2 digits.
15. Reverse input (as in step 12) and check that reading is -100.00mV ±2 digits.
16. Remove voltage source.
17. Set MODE switch to Ω.
18. Connect a known standard resistance of 100.00kΩ to input.
19. Adjust RV2 (Bd 1) for 100.00kΩ.
20. Remove resistance.
21. Set MODE switch to VDC.
22. Apply 100.00V to input terminals.
23. Adjust RV1 (Bd 1) for 100.00V.
24. Increase input slowly to 1000.0V and check that reading is 1000.0V ±0.2V.
25. Remove voltage source.

DC Current Calibration

1. Set MODE switch to ADC.
2. Apply +100 volts in series with 1 megohm.
3. Adjust RV3 (Bd 1) for a reading of +100.00μA.

AC Voltage Calibration

1. Set MODE switch to VAC.
2. Apply 1.0000V at 1kHz to input terminals.
3. Adjust RV2 (Bd 3) for a reading of 1.0000V ±1 digit.
4. Increase input to 100.00V at 1kHz.
5. Adjust RV1 (Bd 3) for a reading of 100.00V ±1 digit.

FUNCTIONAL REPAIR

The following paragraph will detail certain procedures which may be useful in troubleshooting and precautions to be taken.

Fault Isolation

The instrument circuit assembly contains three circuit boards, two display boards and an MOS/LSI integrated circuit, all of which may be interchanged between units to isolate a fault to a particular area. Of course, if only one instrument is available, the isolation may require greater effort.

Power Supply Isolation

Faults which appear as errors in or absence of +6 V or ±17 volts on PC rails designated for these voltages can be isolated by disconnecting the power supply from its load. Solder bridges between TP18 and TP19 and between TP20 and TP21 may be opened with a soldering iron taking care not to overheat the rails and cause lifting. Similarly, the display boards may be unplugged to remove almost all load from the +6 volt supply.

The power supply can then be separately tested by application of a 285 ohm 5 watt resistor to each 17 volt rail and a 24 ohm 5 watt resistor to the +6 volt rail. These simulate actual circuit loads and the power supply fault can then be localized as to the power supply or to circuit loading.

Special Instructions

1. Unprotected M.O.S.T's. TR1/2 (Bd 1) and TR18/25 (Bd 2)

   Whenever installing or removing these components, it is ***essential*** that the wire leads are always shorted together with wire (e.g. fine fuse wire) to protect the device from static breakdown when handled.

2. Reference Zener Diode D13 (Bd 1)

Whenever zener diode D13 is replaced, the following set-up procedure should be adopted.

a. Using a desoldering tool, carefully remove any existing solder bridging solder pads 'A' and 'B' on board 1, to the rear of RV5 and RV6 (A is in front of B) (refer to Figure 6-1 for location).

b. Adjust RV5 (Bd 1) to approximately mid-range.

c. Using a DVM, monitor TP8.

(1) If reading < 9.95V, short circuit R37 by bridging pad 'B'.
If reading > 9.95V, solder pad 'B' and go to step d below.

(2) If reading still < 9.95V, remove short circuit from pad 'B' and then short circuit R36 by bridging pad 'A'.
If reading >9.95V, solder pad 'A' and go to step d below.

(3) If reading still < 9.95V, short circuit both R36 and R37 by bridging pads 'A' and 'B' together.
If reading > 9.95V, solder pads 'A' and 'B' and go to step d below.
If reading still < 9.95V, replace D13 and start again at step a above.

d. When TP8 reads > 9.95V, adjust RV5 (Bd 1) for a reading of 10.000V.

e. Remove test equipment.

3. F.E.T's. Ref. TR18/19 (Bd 2)

These transistors are mounted on small blue pads made of Beryllium Oxide.

WARNING

Great care should be taken not to crush or cut these pads due to the highly toxic nature of beryllium oxide dust.

4. Selected F.E.T's. TR13-15 & 21 (Bd 2)

Whenever any one of these components are replaced, it is ***essential*** to replace the whole set.

5. Clock Circuit (Bd 2)

It is important, when testing this circuitry, not to short any of the logic element connections to the OV rails, since this action could apply a minimum level of -12V to the element and almost certainly damage it. It is recommended that the -17V rail should be used as a return path for test equipment and make appropriate adjustments to indicated readings.

SECTION 7

DRAWINGS AND PARTS LIST

This section contains drawings, schematics diagrams and parts list for this instrument.

Figure 7-1. Assembly

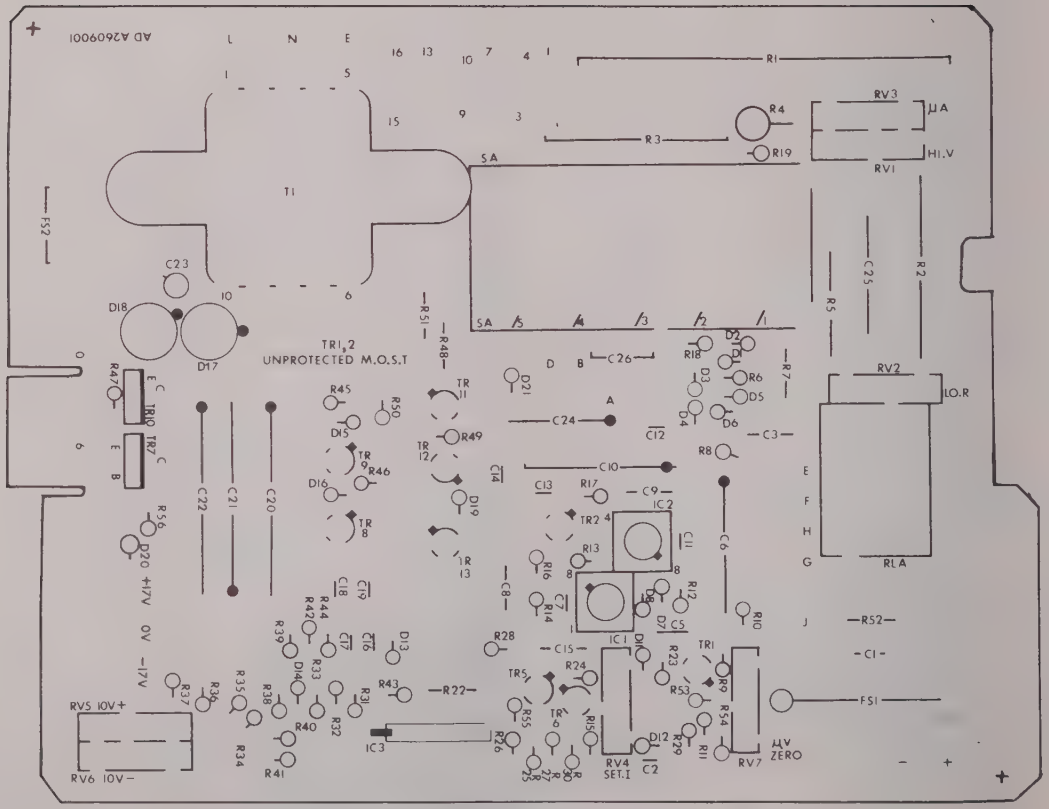


Figure 7-2. Amplifier and Mode Switching Board Assy, Board 1

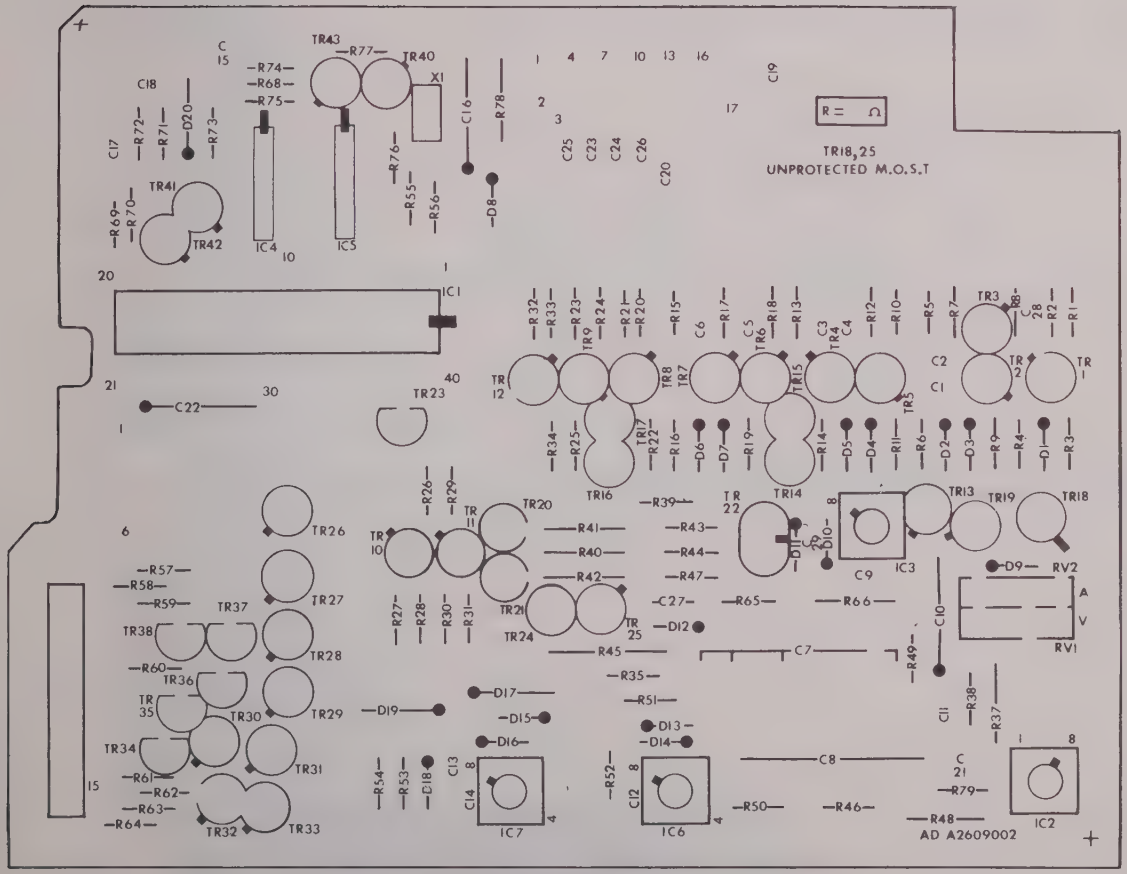


Figure 7-3. A/D Converter Board Assy, Board 2

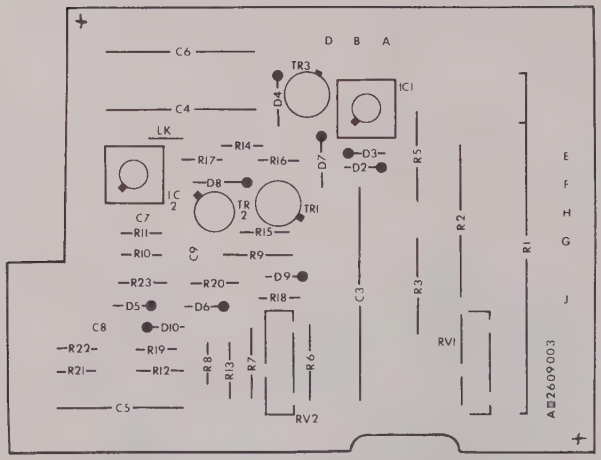


Figure 7-4. AC/DC Converter Assy, Board 3

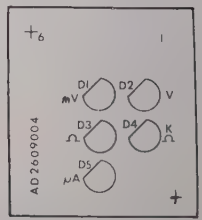


Figure 7-5. Annunciator Board Assy, Board 4

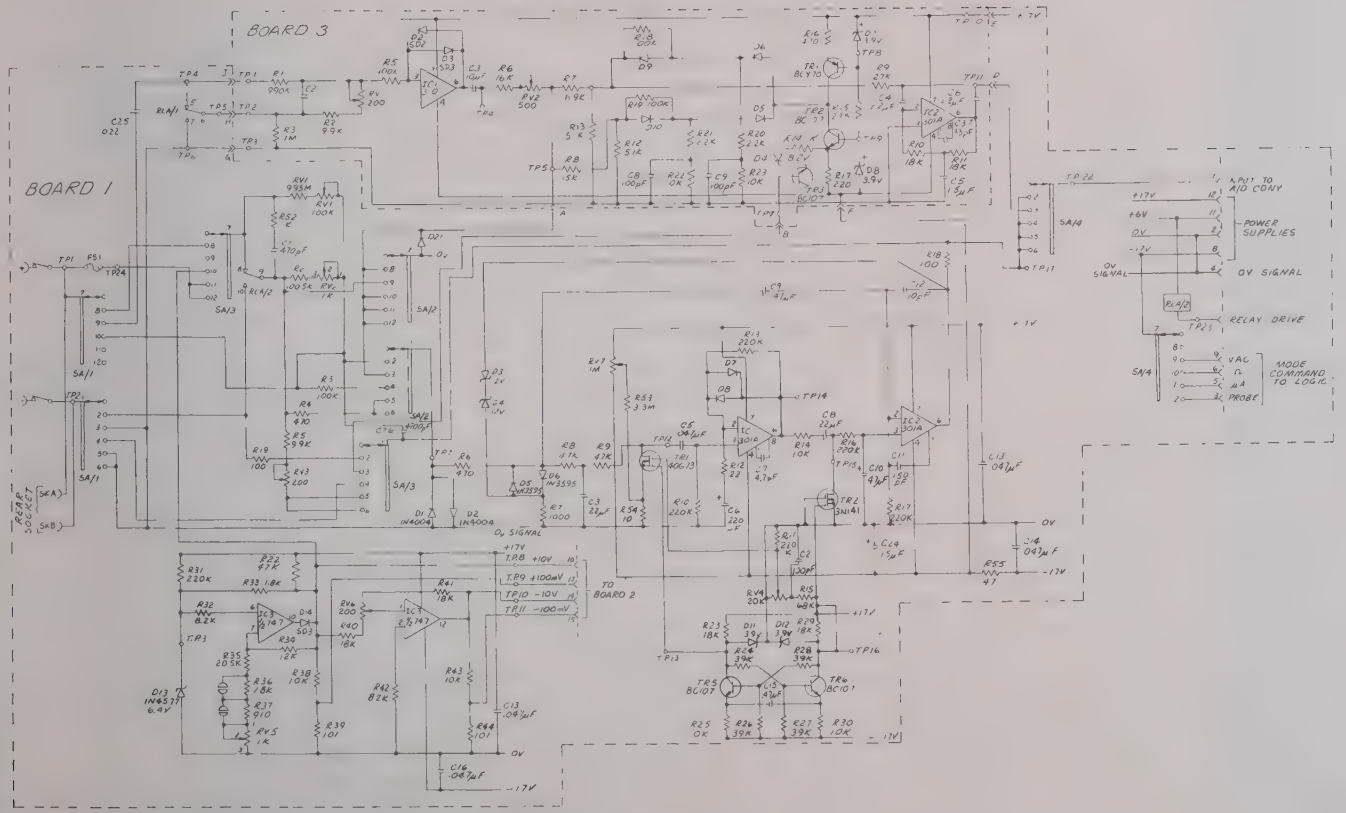


Figure 7-6. Schematic Diagram — Amplifier and Mode Switching, Boards 1 & 3

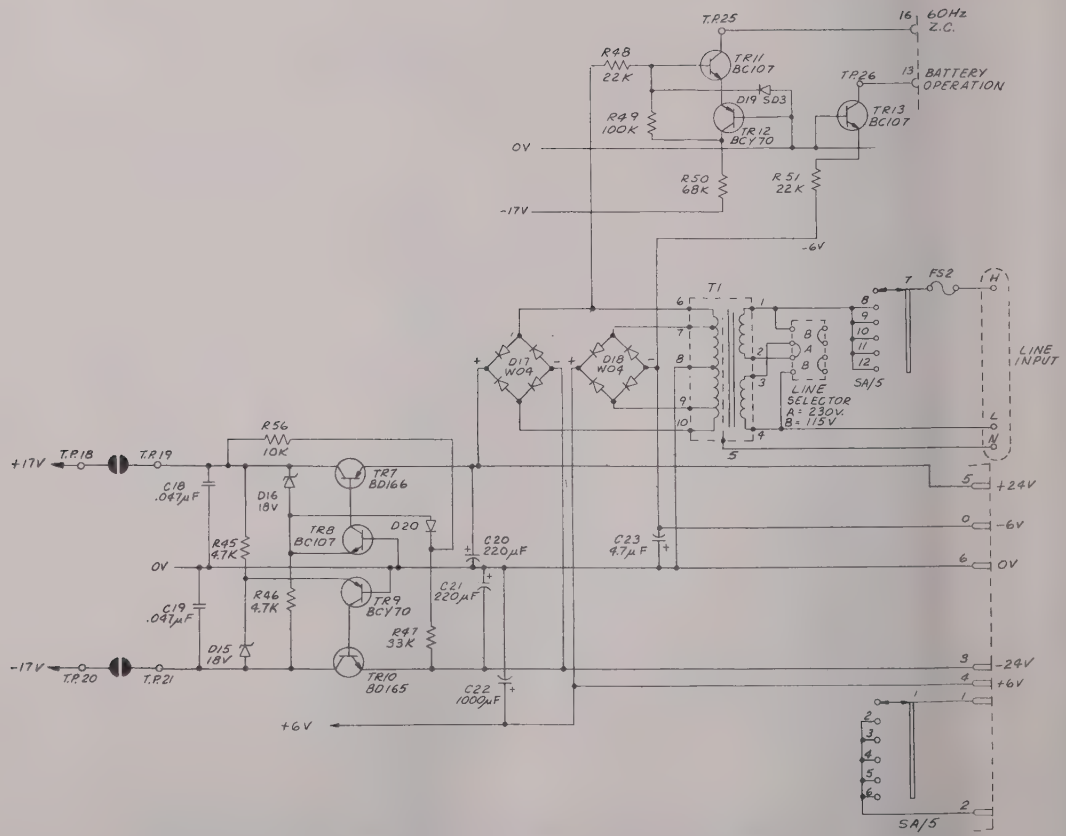


Figure 7-7. Schematic Diagram — Power Supply and Support Circuitry, Board 1

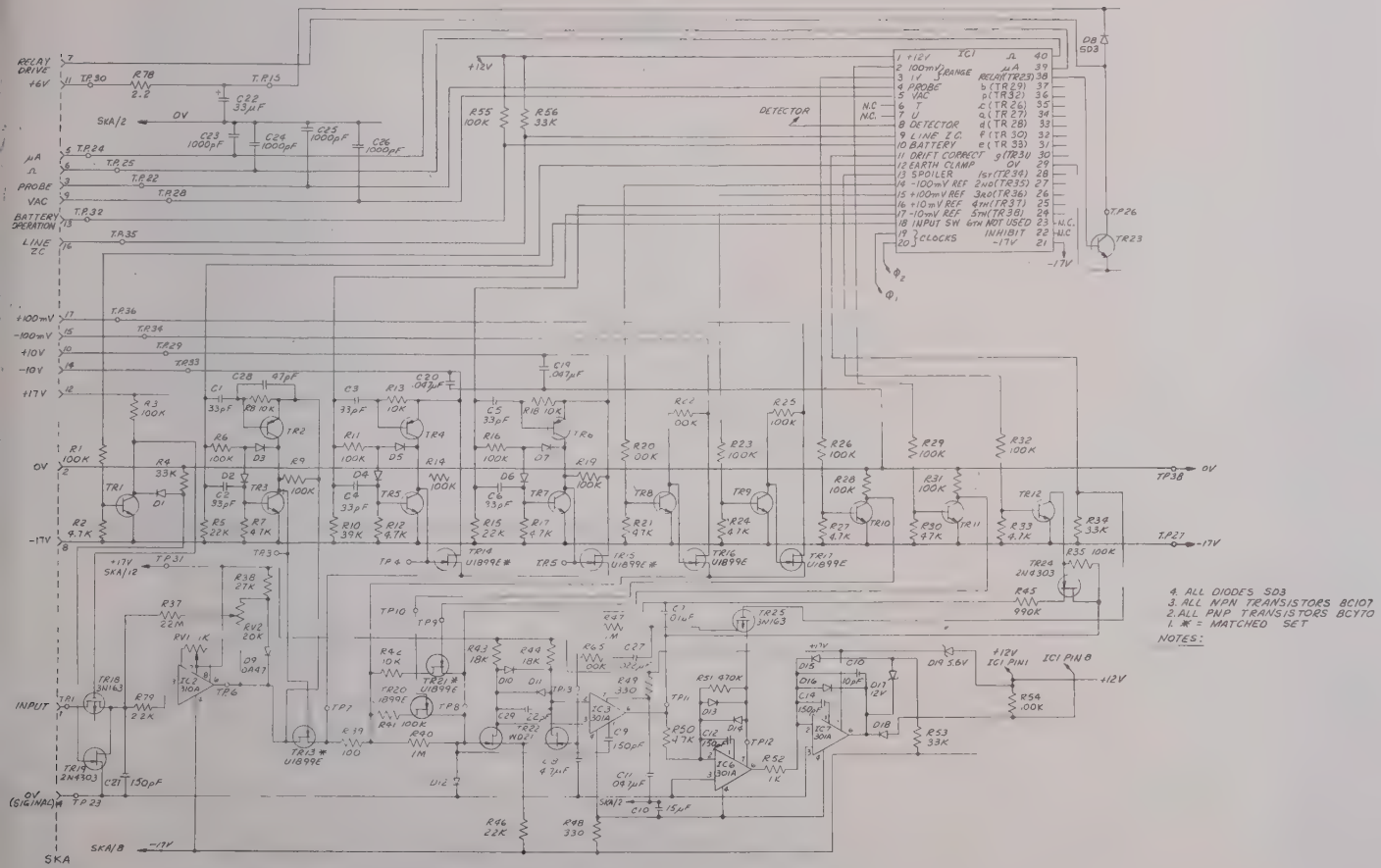


Figure 7-8. Schematic Diagram – A/D Converter, Board 2

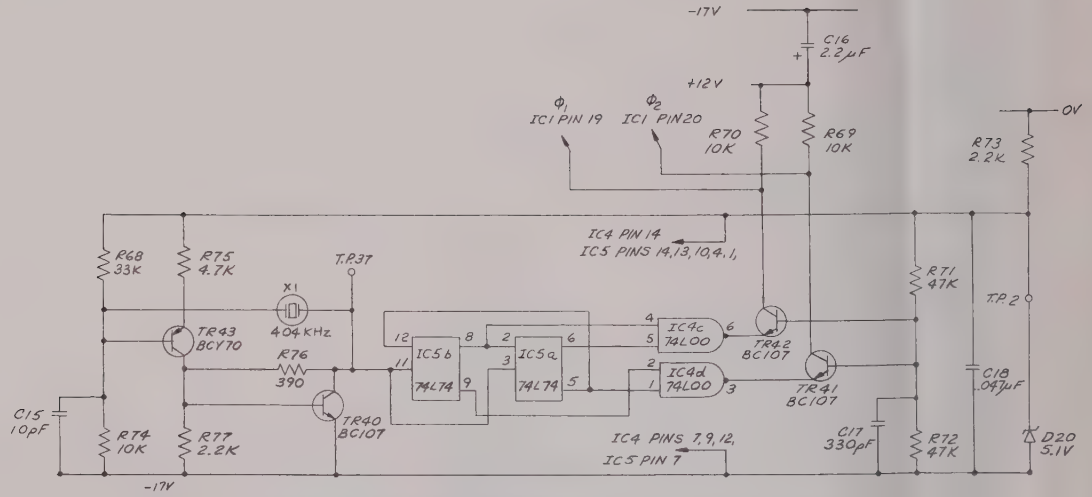


Figure 7-9. Schematic Diagram – Clock Oscillator, Board 2

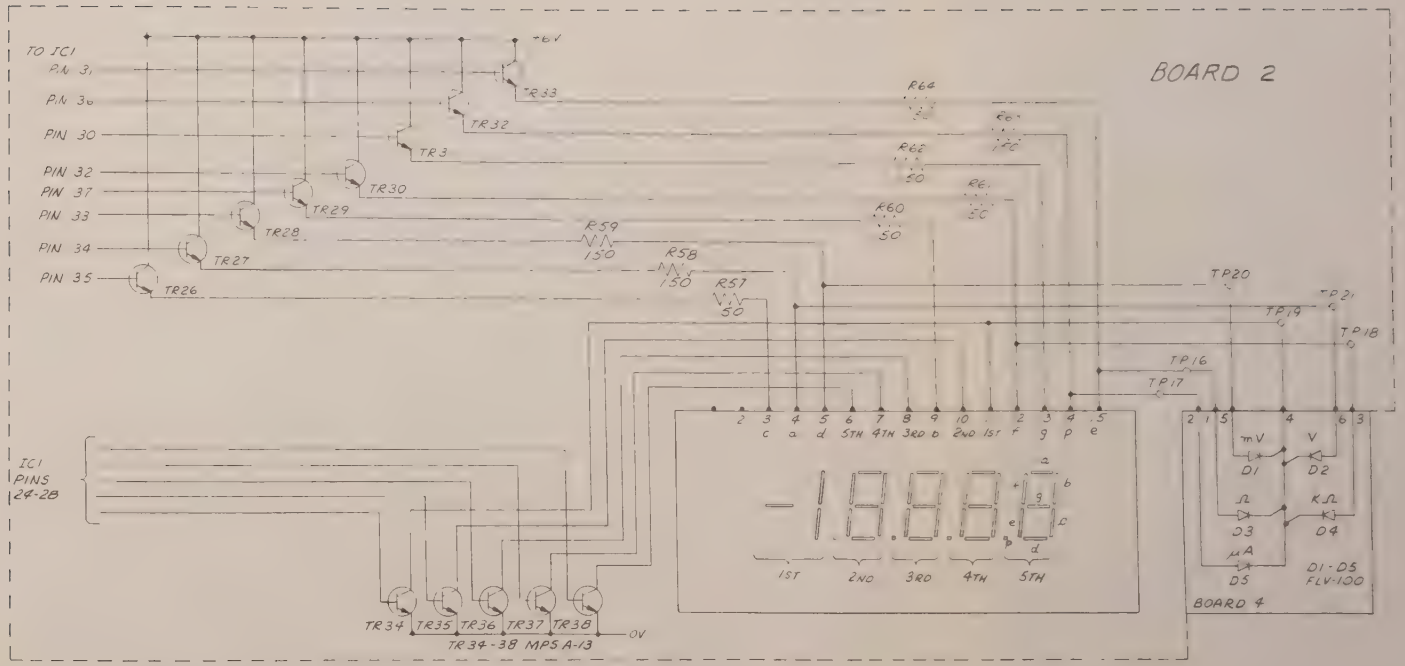


Figure 7-10. Schematic Diagram – Display/Driver Circuitry, Boards 2 & 4

ITEM NO.	DESCRIPTION	PART NO.
	ASSEMBLY (Ref Figure 7-1)	
1	MULTIMETER (WS275645)	2600003
2	PANEL, FRONT, DIAL	2600053
3	SOCKET, FUSE (WS272134-024)	360208080
4	SPRING (WS271054-024)	419600401
5	FUSE, 50mA(FS1) (Alternate 1/32 amp Littlefuse 361.031) (WS26368-001)	360190080
6	KNOB (WS267331-901)	400001790
7	ROLLER, DETENT (WS267334-001)	470111100
8	SPRING, DETENT (WS267333-001)	423010220
9	HANDLE (WS272121-001)	429700301
10	SCREW, THUMB (WS272142-024)	409982150
11	CASE, MODIFIED	2600046
12	PANEL, REAR	2600054
13	PLATE, COVER	2600021
14	PLATE, SHIELD	2609006
15	SCREW, PAN HD.	406804101
16	SCREW, SELF-TAPPING	408813000
17	BOARD ASSY, ANNUNCIATOR, Board 4	2609004
18	BOARD ASSY, A/D CONVERTER, Board 2	2609002
19	SCREW, PAN HD.	406803160
20	SCREW, PAN HD.	406803060
21	WASHER	411129010
22	PLATE, SHIELD	2600036
23	SPACER	2600035
24	BOARD ASSY, AC/DC CONVERTER, Board 3	2609003
25	SHAFT, EXTENSION	2600016

ITEM NO.	DESCRIPTION	PART NO.
26	CONNECTOR, Boards 1 and 3	2600039
27	CONNECTOR, Boards 1 and 2	2600038
28	SELECTOR, LINE VOLTAGE	2600008
29	FUSE, 100mA(FS2) (Alternate 1/8 amp Littlefuse 361.125)	360190120
30	SUPPORT (WS272969-001)	300584730
31	BOARD ASSY, AMPLIFIER AND MODE SWITCHING, Board 1	2609001

AMPLIFIER & MODE SWITCHING BOARD ASSY, Board 1
(Ref Figures 7-2, 7-6, 7-7)

REF SYMBOL		
C1	CAPACITOR, CERAMIC, 470pF ±20%, 1500 WVDC	208450090
C2	CAPACITOR, CERAMIC, 100pF ±20%, 500 WVDC	241321000
C3	CAPACITOR, RECTIFIER, 0.22μF ±10%, 100 WVDC	225452200
C5	CAPACITOR, RECTIFIER, 0.047μF ±10%, 100 WVDC	225444700
C6	CAPACITOR, ELECTROLYTIC, 220μF ±20%, 10 WVDC	273182200
C7	CAPACITOR, CERAMIC, 4.7pF ±20%, 500 WVDC	241304700
C8	CAPACITOR, RECTIFIER, 0.22μF ±10%, 100 WVDC	225452200
C9	CAPACITOR, RECTIFIER, 0.47μF ±10%, 63 WVDC	225154700
C10	CAPACITOR, ELECTROLYTIC, 47μF ±20%, 20 WVDC	265874700
C11	CAPACITOR, CERAMIC, 150pF ±20%, 500 WVDC	241321500
C12	CAPACITOR, CERAMIC, 10pF ±20%, 500 WVDC	241311000
C13	CAPACITOR, CERAMIC, 0.047μF +50 -25%, 25 WVDC	241944700
C14	CAPACITOR, CERAMIC, 0.047μF +50 -25%, 25 WVDC	241944700
C15	CAPACITOR, RECTIFIER, 0.47μF ±10%, 63 WVDC	225154700
C16	CAPACITOR, CERAMIC, 0.047μF +50 -25%, 25 WVDC	241944700
C17	CAPACITOR, CERAMIC, 0.047μF +50 -25%, 25 WVDC	241944700
C18	CAPACITOR, CERAMIC, 0.047μF +50 -25%, 25 WVDC	241944700

REF SYMBOL	DESCRIPTION	PART NO.
C19	CAPACITOR, CERAMIC, 0.047μF +50 -25%, 25 WVDC	241944700
C20	CAPACITOR, ELECTROLYTIC, 220μF, 40 WVDC	273782200
C21	CAPACITOR, ELECTROLYTIC, 220μF, 40 WVDC	273782200
C22	CAPACITOR, ELECTROLYTIC, 1000μF, 10 WVDC	273191000
C23	CAPACITOR, TANTALUM, 4.7μF ±20%, 10 WVDC	265464700
C24	CAPACITOR, TANTALUM, 15μF ±20%, 20 WVDC	265871500
C25	CAPACITOR, RECTIFIER, 0.22μF ±20%, 400 WVDC	226152200
C26	CAPACITOR, RECTIFIER, 4700pF ±10%, 400 WVDC	227434700
D1	DIODE, SD3	300522160
D2	DIODE, SD3	300522160
D3	DIODE, ZENER, 12V ±5%, 0.4 watt	300521480
D4	DIODE, ZENER, 12V ±5%, 0.4 watt	300521480
D5	DIODE, 1N3595	300523590
D6	DIODE, 1N3595	300523590
D7	DIODE, SD3	300522160
D8	DIODE, SD3	300522160
D11	DIODE, ZENER, 3.9V ±5%, 0.4 watt	300521420
D12	DIODE, ZENER, 3.9V ±5%, 0.4 watt	300521420
D13	DIODE, 1N4577	300525050
D14	DIODE, SD3	300522160
D15	DIODE, ZENER, 18V ±2%, 0.4 watt	300525040
D16	DIODE, ZENER, 18V ±2%, 0.4 watt	300525040
D17	BRIDGE, RECTIFIER WO4	300524700
D18	BRIDGE, RECTIFIER WO4	300524700
D19	DIODE, SD3	300522160
D20	DIODE, SD3	300522160
D21	DIODE, SD3	300522160

REF SYMBOL	DESCRIPTION	PART NO.
IC1	INTEGRATED CIRCUIT, LM301AH	510000620
IC2	INTEGRATED CIRCUIT, LM301AH	510000620
IC3	INTEGRATED CIRCUIT, LM747CD	510090020
R1	RESISTOR, 9.95M ohms ±0.25%, 2 watts (Matched Set)	169603802
R2	RESISTOR, 100.5k ohms ±0.25%, 1 watt (Matched Set)	
R3	RESISTOR, 100k ohms ±1%, 1 watt	198751002
R4	RESISTOR, 470 ohms ±10%, 2 watts	172524700
R5	RESISTOR, 9.9k ohms ±0.2%, 1/4 watt	160400363
R6	RESISTOR, 470 ohms ±10%, 1/2 watt	172024700
R7	RESISTOR, 1k ohms ±10%, 1/4 watt	172031000
R8	RESISTOR, 47k ohms ±10%, 1/4 watt	172044700
R9	RESISTOR, 47k ohms ±10%, 1/4 watt	172044700
R10	RESISTOR, 220k ohms ±10%, 1/4 watt	172052200
R11	RESISTOR, 220k ohms ±10%, 1/4 watt	172052200
R12	RESISTOR, 22 ohms ±10%, 1/4 watt	172012200
R13	RESISTOR, 220k ohms ±10%, 1/4 watt	172052200
R14	RESISTOR, 10k ohms ±10%, 1/4 watt	172041000
R15	RESISTOR, 68k ohms ±10%, 1/4 watt	172046800
R16	RESISTOR, 220k ohms ±10%, 1/4 watt	172052200
R17	RESISTOR, 220k ohms ±10%, 1/4 watt	172052200
R18	RESISTOR, 100 ohms ±10%, 1/4 watt	172021000
R19	RESISTOR, 100 ohms ±10%, 1/4 watt	172021000
R22	RESISTOR, 47k ohms ±10%, 1/4 watt	172044700
R23	RESISTOR, 18k ohms ±10%, 1/4 watt	172041800
R24	RESISTOR, 39k ohms ±10%, 1/4 watt	172043900
R25	RESISTOR, 10k ohms ±10%, 1/4 watt	172041000
R26	RESISTOR, 39k ohms ±10%, 1/4 watt	172043900

REF SYMBOL	DESCRIPTION	PART NO.
R27	RESISTOR, 39k ohms ±10%, 1/4 watt	172043900
R28	RESISTOR, 39k ohms ±10%, 1/4 watt	172043900
R29	RESISTOR, 18k ohms ±10%, 1/4 watt	172041800
R30	RESISTOR, 10k ohms ±10%, 1/4 watt	172041000
R31	RESISTOR, 220k ohms ±10%, 1/4 watt	172052200
R32	RESISTOR, 8.2K ohms ±10%, 1/4 watt	172038200
R33	RESISTOR, 1.8k ohms ±1%	192731801
R34	RESISTOR, 12k ohms ±0.5% } Paired	169607901
R35	RESISTOR, 20.5k ohms ±0.5% }	
R36	RESISTOR, 1.8k ohms ±1%	192731801
R37	RESISTOR, 910 ohms ±1%	192729101
R38	RESISTOR, 10k ohms ±0.25%	192841002
R39	RESISTOR, 101 ohms ±0.25%	192821012
R40	RESISTOR, 18k ohms ±0.5% } Paired	169607301
R41	RESISTOR, 18k ohms ±0.5% }	
R42	RESISTOR, 8.2k ohms ±10%, 1/4 watt	172038200
R43	RESISTOR, 10k ohms ±0.2%	192841002
R44	RESISTOR, 101 ohms ±0.2%	192821012
R45	RESISTOR, 4.7k ohms ±10%, 1/4 watt	172034700
R46	RESISTOR, 4.7k ohms ±10%, 1/4 watt	172034700
R47	RESISTOR, 33k ohms ±10%, 1/4 watt	172043300
R48	RESISTOR, 22k ohms ±10%, 1/4 watt	172042200
R49	RESISTOR, 100k ohms ±10%, 1/4 watt	172051000
R50	RESISTOR, 68k ohms ±10%, 1/4 watt	172046800
R51	RESISTOR, 22k ohms ±10%, 1/4 watt	172042200
R52	RESISTOR, 1k ohms ±10%, 1/4 watt	172031000
R53	RESISTOR, 1.5M ohms ±10%, 1/4 watt	172061500

REF SYMBOL	DESCRIPTION	PART NO.
R54	RESISTOR, 10 ohms ±10%, 1/4 watt	172011000
R55	RESISTOR, 47 ohms ±10%, 1/4 watt	172014700
R56	RESISTOR, 10k ohms ±10%, 1/4 watt	172041000
RV1	RESISTOR, VARIABLE, 100k ohms ±10%	130651000
RV2	RESISTOR, VARIABLE, 1k ohms ±10%	130631000
RV3	RESISTOR, VARIABLE, 200 ohms ±10%	130622000
RV4	RESISTOR, VARIABLE, 20k ohms ±10%	130642000
RV5	RESISTOR, VARIABLE, 1k ohms ±10%	130631000
RV6	RESISTOR, VARIABLE, 200 ohms ±10%	130622000
RV7	RESISTOR, VARIABLE, 1M ohms ±10%	130661000
RLA	RELAY	301201502
SA	SWITCH, ROTARY	379605003
SKA	SOCKET, RED	351501100
SKB	SOCKET, BLUE	351501110
T1	TRANSFORMER	309602404
TR1	TRANSISTOR 40673	300555210
TR2	TRANSISTOR 3N141	300554210
TR5	TRANSISTOR BC107	300553320
TR6	TRANSISTOR BC107	300553320
TR7	TRANSISTOR BD166	300555150
TR8	TRANSISTOR BC107	300553320
TR9	TRANSISTOR BCY70	300553590
TR10	TRANSISTOR BD165	300555160
TR11	TRANSISTOR BC107	300553320
TR12	TRANSISTOR BCY70	300553590
TR13	TRANSISTOR BC107	300553320

REF SYMBOL	DESCRIPTION	PART NO.
	A/D CONVERTER BOARD ASSY, Board 2 (Ref Figures 7-3, 7-8, 7-9, 7-10)	
C1	CAPACITOR, CERAMIC, 33pF ±20%, 500 WVDC	241313300
C2	CAPACITOR, CERAMIC, 33pF ±20%, 500 WVDC	241313300
C3	CAPACITOR, CERAMIC, 33pF ±20%, 500 WVDC	241313300
C4	CAPACITOR, CERAMIC, 33pF ±20%, 500 WVDC	241313300
C5	CAPACITOR, CERAMIC, 33pF ±20%, 500 WVDC	241313300
C6	CAPACITOR, CERAMIC, 33pF ±20%, 500 WVDC	241313300
C7	CAPACITOR, POLYSTYRENE, 0.1μF ±1%, 63 WVDC	208100180
C8	CAPACITOR, POLYSTYRENE, 4.7μF±10%, 63 WVDC	219964700
C9	CAPACITOR, CERAMIC, 150pF ±20%, 500 WVDC	241321500
C10	CAPACITOR, TANTALUM, 15μF ±20%, 20 WVDC	265871500
C11	CAPACITOR, CERAMIC, 0.047μF +50 -20%, 25 WVDC	241944700
C12	CAPACITOR, CERAMIC, 150pF ±20%, 500 WVDC	241321500
C13	CAPACITOR, CERAMIC, 10pF ±20%, 500 WVDC	241311000
C14	CAPACITOR, CERAMIC, 150pF ±20%, 500 WVDC	241321500
C15	CAPACITOR, CERAMIC, 10pF ±20%, 500 WVDC	241311000
C16	CAPACITOR, ELECTROLYTIC, 22μF ±20%, 35 WVDC	266072200
C17	CAPACITOR, CERAMIC, 330pF ±20%, 500 WVDC	241323300
C18	CAPACITOR, CERAMIC, 0.047μF +50 -25%, 25 WVDC	241944700
C19	CAPACITOR, CERAMIC, 0.047μF +50 -25%, 25 WVDC	241944700
C20	CAPACITOR, CERAMIC, 0.047μF +50 -25%, 25 WVDC	241944700
C21	CAPACITOR, CERAMIC, 150pF ±20%, 500 WVDC	241321500
C22	CAPACITOR, TANTALUM, 33μF ±20%, 10 WVDC	265473300
C23	CAPACITOR, CERAMIC, 1000pF ±20%, 500 WVDC	241331000
C24	CAPACITOR, CERAMIC, 1000pF ±20%, 500 WVDC	241331000
C25	CAPACITOR, CERAMIC, 1000pF ±20%, 500 WVDC	241331000

REF SYMBOL	DESCRIPTION	PART NO.
C26	CAPACITOR, CERAMIC, 1000pF ±20%, 500 WVDC	241331000
C27	CAPACITOR, POLYESTER, 0.022μF ±10%, 100 WVDC	225442200
C28	CAPACITOR, CERAMIC, 47pF ±10%, 500 WVDC	241314700
C29	CAPACITOR, CERAMIC, 22pF ±10%, 500 WVDC	241312200
D1	DIODE, SD3	300522160
D2	DIODE, SD3	300522160
D3	DIODE, SD3	300522160
D4	DIODE, SD3	300522160
D5	DIODE, SD3	300522160
D6	DIODE, SD3	300522160
D7	DIODE, SD3	300522160
D8	DIODE, SD3	300522160
D9	DIODE, OA47	300520850
D10	DIODE, SD3	300522160
D11	DIODE, SD3	300522160
D12	DIODE, SD3	300522160
D13	DIODE, SD3	300522160
D14	DIODE, SD3	300522160
D15	DIODE, SD3	300522160
D16	DIODE, SD3	300522160
D17	DIODE, ZENER, 12V ±5%, 0.4 watt	300521480
D18	DIODE, SD3	300522160
D19	DIODE, ZENER, 6.8V ±5%, 0.4 watt	300522540
D20	DIODE, ZENER, 5.1V ±5%, 0.4 watt	300521310
IC1	INTEGRATED CIRCUIT, MOS LOGIC	519600303
IC2	INTEGRATED CIRCUIT, LM310H	510090040

REF SYMBOL	DESCRIPTION	PART NO.
IC3	INTEGRATED CIRCUIT, LM301AH	510000620
IC4	INTEGRATED CIRCUIT, SN74L00	510001030
IC5	INTEGRATED CIRCUIT, SN74L74	510001110
IC6	INTEGRATED CIRCUIT, LM301AH	510000620
IC7	INTEGRATED CIRCUIT, LM301AH	510000620
R1	RESISTOR, 100k ohms ±10%, 1/4 watt	172051000
R2	RESISTOR, 4.7k ohms ±10%, 1/4 watt	172034700
R3	RESISTOR, 100k ohms ±10%, 1/4 watt	172051000
R4	RESISTOR, 33k ohms ±10%, 1/4 watt	172043300
R5	RESISTOR, 22k ohms ±10%, 1/4 watt	172042200
R6	RESISTOR, 100k ohms ±10%, 1/4 watt	172051000
R7	RESISTOR, 4.7k ohms ±10%, 1/4 watt	172034700
R8	RESISTOR, 10k ohms ±10%, 1/4 watt	172041000
R9	RESISTOR, 100k ohms ±10%, 1/4 watt	172051000
R10	RESISTOR, 39k ohms ±10%, 1/4 watt	172043900
R11	RESISTOR, 100k ohms ±10%, 1/4 watt	172051000
R12	RESISTOR, 4.7k ohms ±10%, 1/4 watt	172034700
R13	RESISTOR, 10k ohms ±10%, 1/4 watt	172041000
R14	RESISTOR, 100k ohms ±10%, 1/4 watt	172051000
R15	RESISTOR, 15k ohms ±10%, 1/4 watt	172041500
R16	RESISTOR, 100k ohms ±10%, 1/4 watt	172051000
R17	RESISTOR, 4.7k ohms ±10%, 1/4 watt	172034700
R18	RESISTOR, 10k ohms ±10%, 1/4 watt	172041000
R19	RESISTOR, 100k ohms ±10%, 1/4 watt	172051000
R20	RESISTOR, 100k ohms ±10%, 1/4 watt	172051000
R21	RESISTOR, 4.7k ohms ±10%, 1/4 watt	172034700

REF SYMBOL	DESCRIPTION	PART NO.
R22	RESISTOR, 100k ohms ±10%, 1/4 watt	172051000
R23	RESISTOR, 100k ohms ±10%, 1/4 watt	172051000
R24	RESISTOR, 4.7k ohms ±10%, 1/4 watt	172034700
R25	RESISTOR, 100k ohms ±10%, 1/4 watt	172051000
R26	RESISTOR, 100k ohms ±10%, 1/4 watt	172051000
R27	RESISTOR, 4.7k ohms ±10%, 1/4 watt	172034700
R28	RESISTOR, 100k ohms ±10%, 1/4 watt	172051000
R29	RESISTOR, 100k ohms ±10%, 1/4 watt	172051000
R30	RESISTOR, 4.7k ohms ±10%, 1/4 watt	172034700
R31	RESISTOR, 100k ohms ±10%, 1/4 watt	172051000
R32	RESISTOR, 100k ohms ±10%, 1/4 watt	172051000
R33	RESISTOR, 4.7k ohms ±10%, 1/4 watt	172034700
R34	RESISTOR, 33k ohms ±10%, 1/4 watt	172043300
R35	RESISTOR, 100k ohms ±10%, 1/4 watt	172051000
R37	RESISTOR, 22M ohms ±10%, 1/2 watt	172372200
R38	RESISTOR, 27k ohms ±10%, 1/4 watt	172042700
R39	RESISTOR, 100 ohms ±10%, 1/4 watt	172021000
R40	RESISTOR, 1M ohms ±1%, 1/4 watt	192761002
R41	RESISTOR, 100k ohms ±1%, 1/4 watt	192751002
R42	RESISTOR, 10k ohms ±1%, 1/4 watt	192741002
R43	RESISTOR, 18k ohms ±5%, 1/4 watt	195641800
R44	RESISTOR, 18k ohms ±5%, 1/4 watt	195641800
R45	RESISTOR, 990k ohms ±0.25%, 1/4 watt	160400488
R46	RESISTOR, 22k ohms ±5%, 1/4 watt	195642200
R47	RESISTOR, 1M ohms ±10%, 1/4 watt	172061000
R48	RESISTOR, 100 ohms ±10%, 1/2 watt	172321000
R49	RESISTOR, 330 ohms ±10%, 1/4 watt	172023300

REF SYMBOL	DESCRIPTION	PART NO.
R50	RESISTOR, 4.7k ohms ±10%, 1/4 watt	172034700
R51	RESISTOR, 470k ohms ±10%, 1/4 watt	172054700
R52	RESISTOR, 1k ohm ±10%, 1/4 watt	172031000
R53	RESISTOR, 33k ohms ±10%, 1/4 watt	172043300
R54	RESISTOR, 100k ohms ±10%, 1/4 watt	172051000
R55	RESISTOR, 100k ohms ±10%, 1/4 watt	172051000
R56	RESISTOR, 33k ohms ±10%, 1/4 watt	172043300
R57	RESISTOR, 150 ohms ±10%, 1/4 watt	172021500
R58	RESISTOR, 150 ohms ±10%, 1/4 watt	172021500
R59	RESISTOR, 150 ohms ±10%, 1/4 watt	172021500
R60	RESISTOR, 150 ohms ±10%, 1/4 watt	172021500
R61	RESISTOR, 150 ohms ±10%, 1/4 watt	172021500
R62	RESISTOR, 150 ohms ±10%, 1/4 watt	172021500
R63	RESISTOR, 150 ohms ±10%, 1/4 watt	172021500
R64	RESISTOR, 150 ohms ±10%, 1/4 watt	172021500
R65	RESISTOR, 100k ohms ±10%, 1/4 watt	172051000
R66	RESISTOR, 680k ohms ±5%, 1/4 watt	195456800
R68	RESISTOR, 33k ohms ±5%, 1/4 watt	195643300
R69	RESISTOR, 10k ohms ±10%, 1/4 watt	172041000
R70	RESISTOR, 10k ohms ±10%, 1/4 watt	172041000
R71	RESISTOR, 47k ohms ±10%, 1/4 watt	172044700
R72	RESISTOR, 47k ohms ±10%, 1/4 watt	172044700
R73	RESISTOR, 2, 2k ohms ±10%, 1/4 watt	172032200
R74	RESISTOR, 10k ohms ±5%, 1/4 watt	195641000
R75	RESISTOR, 4.7k ohms ±5%, 1/4 watt	195634700
R76	RESISTOR, 390 ohms ±5%, 1/4 watt	195623900
R77	RESISTOR, 2.2k ohms ±10%, 1/4 watt	172032200

REF SYMBOL	DESCRIPTION	PART NO.
R78	RESISTOR, 2.2 ohms ±10%, 1 watt	172302200
R79	RESISTOR, 2.2k ohms ±10%, 1/4 watt	172032200
RV1	RESISTOR, VARIABLE, 1k ohms ±10%, 3/4 watt	130631000
RV2	RESISTOR, VARIABLE, 20k ohms ±10%, 3/4 watt	130642000
TR1	TRANSISTOR, BC107	300553320
TR2	TRANSISTOR, BCY70	300553590
TR3	TRANSISTOR, BC107	300553320
TR4	TRANSISTOR, BCY70	300553590
TR5	TRANSISTOR, BC107	300553320
TR6	TRANSISTOR, BCY70	300553590
TR7	TRANSISTOR, BC107	300553320
TR8	TRANSISTOR, BC107	300553320
TR9	TRANSISTOR, BC107	300553320
TR10	TRANSISTOR, BC107	300553320
TR11	TRANSISTOR, BC107	300553320
TR12	TRANSISTOR, BC107	300553320
TR13	TRANSISTOR, FET U1899E (SELECTED SET OF 4 FET WITH TR21)	300554320
TR14	TRANSISTOR, FET U1899E (SELECTED SET OF 4 FET WITH TR21)	300554320
TR15	TRANSISTOR, FET U1899E (SELECTED SET OF 4 FET WITH TR21)	300554320
TR16	TRANSISTOR, FET U1899E	300554320
TR17	TRANSISTOR, FET U1899E	300554320
TR18	TRANSISTOR, MOS FET 3N163	300554530
TR19	TRANSISTOR, FET 2N4303	300553160
TR20	TRANSISTOR, FET U1899E	300554320
TR21	TRANSISTOR, FET U1899E (SELECTED WITH TR13-15)	300554320

REF SYMBOL	DESCRIPTION	PART NO.
TR22	TRANSISTOR, DUAL FET WD211	300555060
TR23	TRANSISTOR, S9036	300554560
TR24	TRANSISTOR, FET 2N4303	300553160
TR25	TRANSISTOR, MOS FET 3N163	300554530
TR26	TRANSISTOR, BC107	300553320
TR27	TRANSISTOR, BC107	300553320
TR28	TRANSISTOR, BC107	300553320
TR29	TRANSISTOR, BC107	300553320
TR30	TRANSISTOR, BC107	300553320
TR31	TRANSISTOR, BC107	300553320
TR32	TRANSISTOR, BC107	300553320
TR33	TRANSISTOR, BC107	300553320
TR34	TRANSISTOR, S9036	300554560
TR35	TRANSISTOR, S9036	300554560
TR36	TRANSISTOR, S9036	300554560
TR37	TRANSISTOR, S9036	300554560
TR38	TRANSISTOR, S9036	300554560
TR40	TRANSISTOR, BC107	300553320
TR41	TRANSISTOR, BC107	300553320
TR42	TRANSISTOR, BC107	300553320
TR43	TRANSISTOR, BCY70	300553590
X1	CERAMIC CRYSTAL	301900101
–	DISPLAY, LED	309400201
–	CONNECTOR, EDGE, AMPHENOL 64-18	352515040
–	PAD, TRANSISTOR	300584830

REF SYMBOL	DESCRIPTION	PART NO.
	AC/DC CONVERTER BOARD ASSY, Board 3, (Ref Figures 7-4,7-6)	
C3	CAPACITOR, POLYESTER, 10μF ±20%, 63 WVDC	219971000
C4	CAPACITOR, POLYESTER, 2.2μF ±20%, 63 WVDC	219962200
C5	CAPACITOR, POLYESTER, 1.5μF ±20%, 63 WVDC	219961500
C6	CAPACITOR, POLYESTER, 2.2μF ±20%, 63 WVDC	219962200
C7	CAPACITOR, CERAMIC, 33pF ±20%, 500 WVDC	241313300
C8	CAPACITOR, CERAMIC, 100pF ±20%, 500 WVDC	241321000
C9	CAPACITOR, CERAMIC, 100pF ±20%, 500 WVDC	241321000
D2	DIODE, SD3	300522160
D3	DIODE, SD3	300522160
D4	DIODE, ZENER, 8.2V	300521330
D5	DIODE, HP5082-6221	300525380
D6	DIODE, HP5082-6221	300525380
D7	DIODE, ZENER, 3.9V	300521420
D8	DIODE, ZENER, 3.9V	300521420
D9	DIODE, HP5082-6221	300525380
D10	DIODE, HP5082-6221	300525380
IC1	INTEGRATED CIRCUIT, LM310H	510090040
IC2	INTEGRATED CIRCUIT, LM301AH	510000620
R1	RESISTOR, 990k ohms ±0.5%, 2 watts (MATCHED SET)	169606201
R2	RESISTOR, 9.9k ohms ±0.5%, 1/2 watt (MATCHED SET)	
R3	RESISTOR, 1M ohm ±10%, 2 watts	172561000
R5	RESISTOR, 100k ohms ±10%, 2 watts	172551000

REF SYMBOL	DESCRIPTION	PART NO.
R6	RESISTOR, 16k ohms ±0.5%, 1/4 watt } MATCHED	
R7	RESISTOR, 16.9k ohms ±o.5%, 1/4 watt } SET	169606101
R8	RESISTOR, 15k ohms ±10%, 1/4 watt	172041500
R9	RESISTOR, 27k ohms ±1%, 1/4 watt	192742702
R10	RESISTOR, 18k ohms ±10%, 1/4 watt	172041800
R11	RESISTOR, 18k ohms ±10%, 1/4 watt	172041800
R12	RESISTOR, 5.1k ohms ±1%, 1/16 watt	192635102
R13	RESISTOR, 5.1k ohms ±1%, 1/16 watt	192635102
R14	RESISTOR, 1k ohms ±10%, 1/4 watt	172031000
R15	RESISTOR, 27k ohms ±10%, 1/4 watt	172042700
R16	RESISTOR, 470 ohms ±5%, 1/4 watt	195624700
R17	RESISTOR, 220 ohms ±5%, 1/4 watt	195622200
R18	RESISTOR, 100k ohms ±10%, 1/4 watt	172051000
R19	RESISTOR, 100k ohms ±10%, 1/4 watt	172051000
R20	RESISTOR, 2.2k ohms ±10%, 1/4 watt	172032200
R21	RESISTOR, 2.2k ohms ±10%, 1/4 watt	172032200
R22	RESISTOR, 10k ohms ±10%, 1/4 watt	172041000
R23	RESISTOR, 10k ohms ±10%, 1/4 watt	172041000
RV1	RESISTOR, VARIABLE, 200 ohms ±10%, 3/4 watt	130622000
RV2	RESISTOR, VARIABLE, 500 ohms ±10%, 3/4 watt	130625000
TR1	TRANSISTOR, BCY70	300553590
TR2	TRANSISTOR, BC107A	300553320
TR3	TRANSISTOR, BC107A	300553320

REF SYMBOL	DESCRIPTION	PART NO.
	ANNUNCIATOR BOARD ASSY, Board 4 (Ref Figures 7-5, 7-10)	
D1	DIODE, FLV100	300750030
D2	DIODE, FLV100	300750030
D3	DIODE, FLV100	300750030
D4	DIODE, FLV100	300750030
D5	DIODE, FLV100	300750030
–	PAD, MOUNTING	300584810

WESTON EQUIPMENT WARRANTY

Weston warrants equipment of its manufacture against defective materials or workmanship for a period of one year from date of shipment.

The liability of Seller under this warranty is limited, at Seller's option, solely to repair, replacement with equivalent Weston equipment, at an appropriate credit adjustment not to exceed the original equipment sales price, of equipment returned to the Seller provided that (a) Seller is promptly notified in writing by Buyer upon discovery of defects, (b) Upon receipt of written authorization from Seller the defective equipment is returned as directed, transportation charges prepaid by Buyer, and (c) Seller's examination of such equipment discloses to his satisfaction that defects were not caused by negligence, misuse, improper installation, accident, or unauthorized repair or alteration by the Buyer.

This warranty does not include mechanical parts failing from normal usage nor does it cover limited life electrical components which deteriorate with age such as tubes, lamps, etc.

This warranty is in lieu of all other warranties, expressed or implied, including the implied warranty of fitness for a particular purpose to the original purchaser or to any other person. Seller shall not be liable for consequential damages of any kind.

The aforementioned provisions do not extend the original warranty period of any article which has been either repaired or replaced by Seller.

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